CRANFIELD UNIVERSITY

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Exploring the project management community paradigm and the role of performance prediction

School of Aerospace, Transport and Manufacturing

PhD
Academic Year: 2009 – 2014

Supervisor: Dr. Peter Ball
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ABSTRACT

‘Project performance’ is the metric of delivering project objectives. This research is motivated by levels of project failure and the purpose of the research is to investigate improved project performance. The scientific spectrum is considered; arguing project management as a sub-field of management science based in ‘design science’. Despite research since the 1950s, there is no established community paradigm for project management, illustrated by multiple ‘schools of thought’ failing to stimulate performance improvement. This is investigated with respect to the changing nature of projects and their management; application in numerous industrial sectors, across increasing scope of the product lifecycle (including service projects), and the changing role of project managers as value adding ‘implementers’ rather than status ‘reporters’.

Methodology examines the community paradigm and identifies the lack of community paradigm and argues that gap spotting is not appropriate. Conducting research that fills knowledge gaps does not identify underlying issues and reinforces fundamental failings. Underlying assumptions are identified and challenged. Key characteristics are examined in the context of requirements of the community paradigm. The purpose of theory is to describe, explain and predict. Some techniques describe and explain. Few, if any, predict. This locates ‘performance prediction’ as the research issue and suggests it is a missing function for performance improvement.

The research focus considers single tasks within a project network. A research model of early stage deviation from plan is developed from the literature on project pathogens and incubation processes. ‘Deviation lifecycle’ as a project function is identified as having no previous evidence in literature. This is developed into a practice model extending the role of failure modes and effects analysis (FMEA) and integrating weak signals and tipping point theory to test performance. Case studies examine representative application of the model and build on the previous cases to illustrate potential for practice. The case studies were reviewed by industrial experts.

The changing role of project managers to value added implementers implies a need to improve performance. Research found potential to understand and predict early stage deviation and develops the deviation lifecycle and research model. Across the case studies the research model illustrated potential application.

Practical implications indicate potential contribution of project management techniques based on prediction rather than traditional reporting. Developing the community paradigm based on design science is discussed as further work.

The originality of the research challenges the lack of theoretical foundation for project management by discussion of the community paradigm and proposes design science as a candidate. The work identifies ‘prediction’ as a relevant but missing function from the project management ‘toolbox’, and introduces the concept of the deviation lifecycle and note no previous literature.

The research develops an industrial research model that extends the application of FMEA to examine ‘performance’ and integrates weak signals and tipping point analysis to manage the resolution.

Keywords:

Project Performance, Design Science, Project Management Community Paradigm, Deviation Lifecycle, Predictive tools / techniques, Performance FMEA, Weak Signals, Tipping Point

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LIST OF ABBREVIATIONS AND ACRONYMS

APM	Association for Project Management
APMBoK	Association for Project Management Body of Knowledge
CIT	Critical Incident Technique
CNC	Computer Numerical Control
DLC-IM	Deviation Life Cycle – Industrial Model
DLC-LM	Deviation Life Cycle – Literature Model
DLC-TM	Deviation Life Cycle – Theoretical Model
EHS	Environment, Health and Safety
EVM	Earned Value Management
EW	Early Warnings
FMEA	Failure Modes and Effects Analysis
IS	Information Systems
IT	Information Technology
KPI	Key Performance Indicators
NASA	National Aeronautics and Space Administration
PM	Project Management
PMI	Project Management Institute
PMBoK	Project Management Institute Body of Knowledge
RPN	Risk Priority Number
TP	Tipping Point
TRL	Technology Readiness Level
WS	Weak Signals

1 Introduction, Scope and Summary

1.1 Introduction

Activities labelled as ‘projects’ are common in many social environments; project management seeks to deliver project objectives. Progress being made by the academic project management community is summarised by Morris:

> *“Almost nothing; nearly all project management writing and research seems to be about means rather than ends. Very little connects with performance”.*
>
> Morris (2013a, preface, page xx)

Motivated by reported project failures, this research explores the “*shortcoming, challenge and opportunity*” (Morris, 2013a, page xx) by investigating how ‘performance’ emerges from project management activities and how tools and techniques are, or can be, developed to improve performance. Generally, ‘performance’ is considered to be the ability to achieve a declared set of activities, measured by a range of metrics. The importance for research to understand project management performance cannot be understated; Bannerman (2013) suggests “*a huge performance gap remains to be overcome*” (Bannerman, 2013, page 4325). Investigation of performance improvement demands analysis of the theoretical foundations of project management and application in practice and recognition of the broadening scope of application and the need to deliver value to stakeholders.

These issues are explored in this research in the context of developing the focused research issue of investigating methods of detecting failure. A potential advantage that might be gained is the opportunity for performance prediction to test a proposed project plan prior to commencing work. Recognising the complexities of the project network, the research is developed by focusing on the behaviour of individual tasks. The overall aim of the research in this thesis is:

> To investigate issues underlying project failure and how tools and techniques to predict performance emerge from project management's theoretical foundations. To conduct research that focuses on detailed analysis and structure required to identify failure sources and detection techniques and develop methodology to guide practitioners to achieve improved project performance.

The research aim identifies two dimensions; the first dimension examines the overall development of the underlying theoretical structure, the second dimension focuses on supporting practice by investigating predictive performance analysis. To fulfil this aim, the focused research question (developed in chapter four) is:

> How can predicting task deviation positively influence improved project performance?

1.2 Scope

The introduction positioned the investigation and stated its overall aim and research question. This section explores the scope of the research, its scientific foundation and discusses its relevance to the challenge of identifying a focused research topic that allows conclusions to be relevant to the general theory.

The authors industrial experience, since the mid-1980s, has been in the aerospace industry working on a range of projects in manufacturing, structural test and integration engineering. This experience identified a clear problem with project delivery performance. The industrial solution would be to apply more control, but more control doesn't work if the underlying fundamentals are wrong. This view led to a personal interest in understanding how projects were delivered. This was developed into the initial proposal for the research presented in this thesis.

Coming from an industrial engineering background, particularly in a relatively conservative industry such as aerospace, a positivist approach was the natural starting point. The expectation being to identify the science underlying the industrial process in order to locate relevant research from which an appropriate topic and research issue would be identified. As a significant portion of the research presented in this thesis shows, the expected approach did not occur due to the lack of underlying theoretical foundation (recognised as the lack of community paradigm) which led to identifying the need to challenge underlying assumptions which proved to be the fundamental area of research from which the research aim and research question was developed.

Understanding where project management should be located in the scientific spectrum provides the first topic to be examined. The initial dimension of the research aim is to investigate issues underlying project performance. Literature review identifies the lack of community paradigm (Kuhn 1996) as critical among a range of topics, which suggests that project management needs to be considered from basic scientific principles.

The second dimension focuses on the emergence of tools and techniques to predict performance from project management's functions and theoretical foundations. Lawrence and Scanlan (2007, page 509) provide a focus: "*modern, complex projects cannot be planned and executed using 50-year-old project management tools"* and discuss why these tools and techniques are part of the problem. For example, continuing to focus on the same thing (e.g. status reporting), but expecting a different result (e.g. a step change in performance) was Einstein's definition of insanity.

The typical project management toolset does not support performance prediction. Rather than waiting until things have gone wrong and then designing and applying correction, focus should be on the initial stages of predicting and detecting a developing 'deviation' and applying mitigation. This indicates that the research focus should be on detailed analysis and structure required to identify failure sources and detection techniques. This suggests that analysing the issues by challenging their underlying assumptions and assessing their contribution to performance prediction will be more relevant. Assessing project management from a functional perspective tests whether prediction is an existing or necessary project function.

Building on the initial literature review and research focus, the next stage is to develop methodology to guide practitioners to achieve improved project performance. Taking the view that prediction is a missing function the research investigates how it might be implemented and develops a research model to conduct illustrative research to indicate how the process might be applied in practice, with example case studies to examine the process.

There is a clear challenge to examine the foundations of project management and the need for development of a community paradigm. This is necessary to support the argument of the need for techniques that assist project performance – i.e. predictive techniques that relate to the research aim and focused research issue and research question.

This is supported by literature: If corporate policy is to use the "*dominant model*" (Winter et al., 2006, page 638), i.e. project management, to implement "*corporate strategy*" (Klopenborg and Opfer, 2002), the need for a "*broad, multi-industry, theoretically grounded explanation*" (Morris, 2000, page 23), remains unresolved (Too and Weaver 2013). Bannerman states: "*improving project delivery remains an important focus for research and practice*" (Bannerman, 2013, page 4325).

1.3 Summary

This section provides a summary of the thesis chapters covering a brief statement of purpose of each chapter and illustrating the relationships between them.

This introduction provides a background to the research issue. Literature review is considered in chapter two. This provides an exploratory analysis of the issues identified in the literature and the industrial environment and examines the practice aspects of the problem area. This identifies the use of project management across multiple sectors and identifies the commonality between various applications.

Chapter three examines the philosophical foundations of project management, its scientific location and development of the overall research methodology. This is structured on the model by Meredith (1993) as developed by Albores-Barajas (2006, page 40). To provide a focused structure the "*probelmatization*" methodology (Alvesson and Sandberg, 2011) is applied to develop the research focus. Chapter three also develops fieldwork methods and focuses on case studies (Yin, 2009) and critical incident technique (Flanagan, 1954).

Chapter four develops the literature review with the objective of defining and stating the research question. This is then developed into the research model; initially by discussion of the specific literature and then from a theoretical perspective. The subsequent section develops it to be useful in an industrial process model. Chapter five carries out the industrial investigation. Following the industrial investigation, analysis is covered in chapter six. The overall research activity is then reviewed in chapter seven.

The layout of chapters, identifying stages of the research process, and the relationship to the methodology is at figure 1.

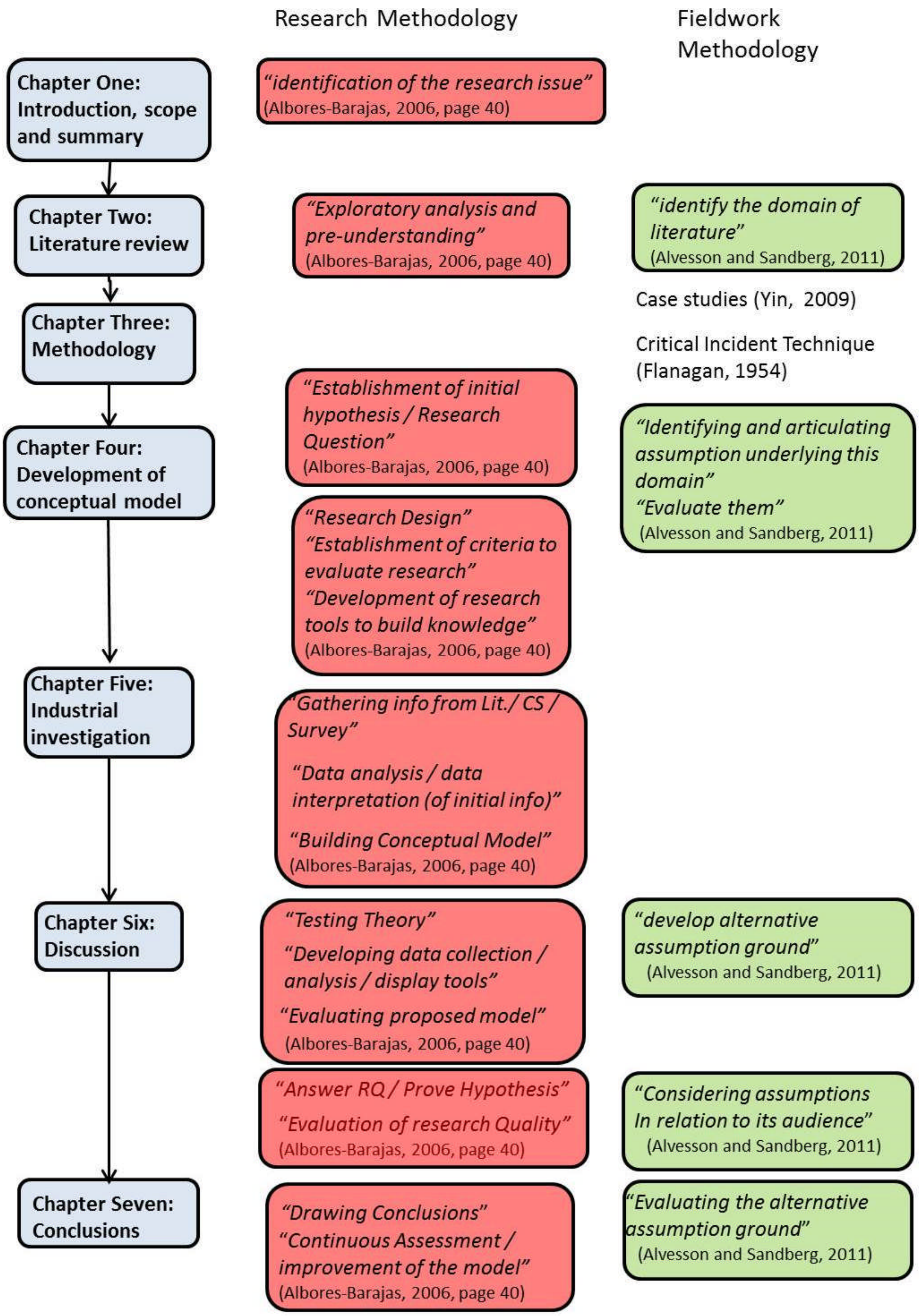

Figure 1: Chapter Layout

2 Literature review

2.1 Introduction

This chapter explores the literature domain (defined in section 2.1.1) to identify evidence and key characteristics that describe the theoretical foundations (sections 2.2 to 2.9) and industrial practice (section 2.10) of project management from which the research focus can be developed.

The history of project management is discussed by several authors; Morris (1997) is considered definitive and, more recently, Kozak-Holland (2011). Others offer summaries (Söderlund, 2004b; Malan, 2006; Weaver, 2007; Burke, 2007; Johnson, 2013). Activities requiring significant organisation, dating back 6,000 years, are often cited (Nicholas and Steyn, 2008; Geraldi et al., 2008), although little evidence exists to describe their management. Weaver (2008, page 2) discusses scheduling and identifies 2,500 year old references. Easterby-Smith et al. (2008, page 3) discusses Menicius (372-289 BC) who identified models, systems and the division of labour; concepts typically believed to be introduced 2,000 years later.

These historical references do not directly contribute to the development of contemporary project management which can be largely bounded within the 20th century, (although traced back to the work of Taylor (1911) and Smith (1789)). *"One of the earliest business management roles that could be defined as 'project management' was the role of Proctor and Gamble's 'brand managers' in the mid to late 1920's"* (Weaver 2007, page 7).

'Modern' project management developed through the 20th century, with the major developments in the post 1950s mapped in Figure 2 (Morris, 2010), the timeline of which provides a baseline for literature review to be located.

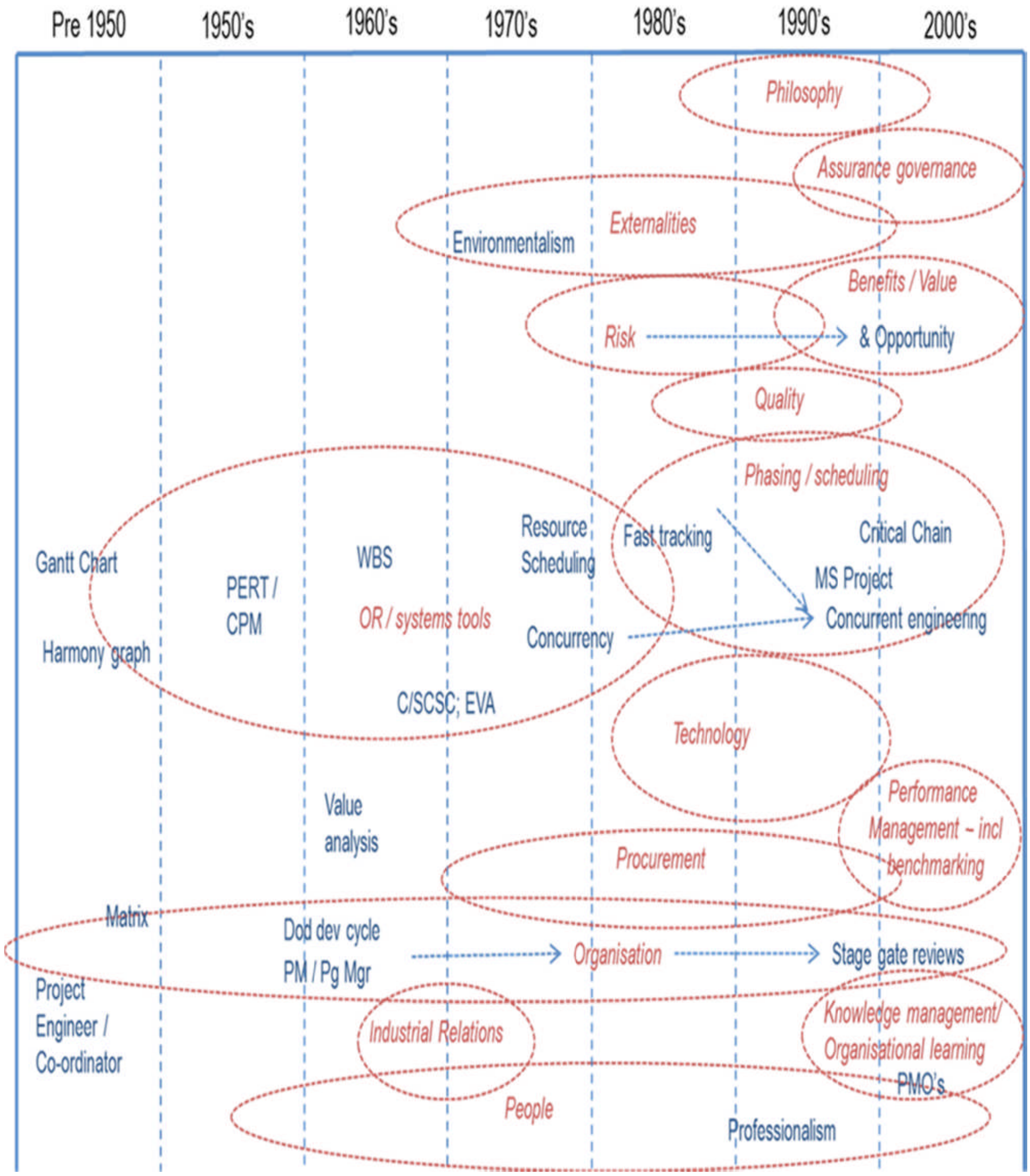

Figure 2: Project Management related research contribution over the past five or more decades (Morris, 2010, page 145)

The objective of literature review is to identify the community paradigms (the purpose of which is discussed by Kuhn, 1996, page 43 and postscript pages 174-210), which can then be analysed to locate knowledge gaps (sections 3.10 and 3.11). This will allow a focused research topic to be defined to test the research aim. This builds on the discussion to fulfil the "*exploratory analysis and pre-understanding*" stage (Albores-Barajas, 2006, page 40).

2.1.1 Literature domain

Identifying the domain of relevant literature is critical (Alvesson and Sandberg, 2011) discussed further in chapter three. For project management the domain is primarily the journals: *Project Management Journal*, *International Journal of Project Management*, and *International Journal of Managing Projects in Business*. Other subject journals are listed on the Australian Institute of Project Management website[1]. However, the volume of literature outside the main project management journals (e.g. Söderlund, 2011, Table 1) is relevant and significantly extends the domain; for example "*The Journal of Management in Engineering*" appears to be, in effect, a project management journal. The volume of literature is a problem; Morris (2010, page 143) suggests; "*what you can measure is just a sub-set of what you can see, and what you can see is just a sub-set of what is there*". The challenge is to ensure that the literature review is sufficiently broad to capture and synthesise the issues such that the derived research issue can be integrated into the general theory. Within the measurable literature sub-set, identifying key characteristics that provide the foundation for research is the first challenge. The second challenge is to test literature for rigour, relevance and to select articles that make the broadest and highest quality contribution. This prompts the question: What defines project management research? Kloppenborg and Opfer (2002, page 6) suggest:

> *"Project management research is defined to include published works that are based upon data (either primary or secondary) and that makes generalizable [sic] conclusions drawn from the data, where the data and conclusions are focused on either the project management context or the management activities (not the technical activities) needed to complete a project successfully".*
>
> Kloppenborg and Opfer (2002, page 6)

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[1] http://www.aipm.com.au/

To investigate this subject, the literature focus is on project management tools and techniques as practised post year 2000, with the historical context being explored when specific issues require.

A note of caution: the Standish organisations ‘Chaos’ reports (e.g. Standish, 1994), are widely cited, directly or indirectly. Glass (2005, 2006) and Jørgensen and Moløkken-Østvold (2006) challenge the validity of these reports. Eveleens and Verhoef (2010) suggest *“four major problems: they’re misleading, one-sided, pervert the estimation practice, and result in meaningless figures”*. These reports will not be cited directly in this research. However it is very difficult, if not impossible, to identify every ‘reference chain’ that traces back to these reports. Where possible, cited papers that reference them will be treated cautiously with respect to the influence of the topics to which reference is made.

2.2 Literature overview

This section provides an analysis of both the breadth of the issues as well as the depth of the detail. The problem is illustrated by Crawford et al. (2006a) who discuss the transitory nature of management; they conclude that “*Similar changes can be seen within the project management literature*” (Crawford et al., 2006a, page 176).

Initially, articles that either reviewed significant numbers of articles or had been widely cited were considered. The risk being multiple uses of common source data, which has not been investigated in detail. Recognising the earlier comment from Morris (2010), review still cannot be exhaustive. Articles published over a 16 year period, collectively examining in the order of 11,500 articles published between 1960 and 2009, were identified: Betts and Lansley (1995) reviewed 337 papers published in the first ten years of the International Journal of Project Management (1982 – 1993), Morris (2000, figure 6, page 16) identifies 750 papers published in International Journal of Project Management between 1990 and 1999 (although three years overlap with Betts and Lansley, 1995). Urli and Urli (2000) studied some 3,565 articles identified in the *“ABI-*

INFORM database from 1987 to 1996" and concluded "*considerable professional interest but a lack of academic interest*".

The pre-2000 period is largely covered by Kloppenborg and Opfer (2002) who utilised publications in the period 1960 – 1999 and identified in excess of 100,000 initial references from which: *"An annotated bibliography was created of 3,554 articles, papers, dissertations, and government research reports"* to document "*trends, major issues, contributions, and the circumstances surrounding past research; to develop an understandable portrayal of how the theory and practice of project management has evolved*". The work of Kloppenborg and Opfer (2002) is supported by more than 50 senior project managers and academics (how many were common with Urli and Urli (2000) has not been identified).

Söderlund (2004b, page 656) follow Betts and Lansley (1995) to review the International Journal of Project Management between 1993 – 2002 and 14 other management and organisation journals but do not identify how many articles were included. Estimated at 940 articles (Crawford et al., 2006a, page 179, figure 1), Crawford et al., (2006a) further review articles in the International Journal of Project Management and Project Management Journal and "*uncovers the trends of emphasis within the project management literature over the period 1994–2003"* (Crawford et al., 2006a, page 175). Kwak and Anbari (2009) focus on 18 business and management journals outside of the mainstream project management literature and investigated 537 articles over the period from the 1950s to the summer of 2007. Söderlund (2011) examined 305 articles published outside the "*conventional project management publications*" (Söderlund, 2011, page 154). In a series of six editorials Bredillet (2007b to 2008c) explores research in Project Management "*in order to draw a mapping of the researches conducted in the field of project management and their main characteristics*", and concludes "*that project management is a recognisable field of study*" and that "*management will be richer for giving it full recognition*" (Bredillet, 2008c, page 4). Some reviews are more focused; for example, based on a study of 448 projects, Dvir and Lechler (2004) examine the impact of change on project plans and argue that "*high quality planning cannot compensate for the negative effects of changes*" (Dvir and Lechler, 2004, page 10-11), and "*the major lesson is: while it is impossible to prevent project changes at all, they should be kept to a minimum*" (Dvir and Lechler, 2004, page 12). Of specific interest to the industrial application, Peippo-Lavikka et al., 2011 reviewed 2,354 articles across 564 journals over the period 1986 – 2009 to analyse the theoretical grounding in nine industrial sectors. These articles provide a limited sub-set of the literature that, due to the range of articles cited is considered to provide a broad overview of the literature.

An alternative perspective to analysing project management research is offered by Kwak and Anbari (2009). Similar to Söderlund (2011), they focus on management journals outside of the mainstream project management literature. They identified strong utilisation within practical applications (Construction, engineering, manufacturing systems) but less recognition within the management domain. Kwak and Anbari (2009) comment on Kloppenberg and Opfer (2002) "*They concluded that project management has extensive current opportunities and a bright future*" (Kwak and Anbari, 2009, page 436). Whilst "*extensive current opportunities"* is good news for research, the volume of literature does pose a challenge for the identification of focused research issues, and supports the need for a structured approach to sense making and derivation of relevant issues.

Crawford et al. (2006a) and Söderlund (2011) develop the analysis of Kloppenborg and Opfer (2002) and both examine a similar research topic and expand the scope by conducting meta-analysis of trends:

- Crawford et al. (2006a) provides a "*Comparison of identified trends in project management*" (Crawford et al., 2006a, page 177, Table 1) based on review of seven studies: Betts and Lansley (1995) (covered 1983 – 1992), Themistocleous and Wearne (2000) (covered 1984 – 1998), Zobel and Wearne (2000) (1996 – 1998), Morris et al. (2000), Morris (2000), Urli and Urli (2000), Kloppenborg and Opfer (2000). Relevant to this research, project performance is one of the few trends, amongst 43 identified

(Crawford et al., 2006a, page 177, table 1), that shows an increase, although there are conflicting arguments offered by different authors, for example on organisational change.

- Söderlund (2011) follows the approach of Leybourne (2007) and "*addresses overall management and organization topics in projects and project management*" and offers an overview that "*builds on a series of prior literature reviews and database investigations*": (Crawford et al., (2006a), Engwall (1998), Ford and Randolph (1992), Packendorff (1995), Shenhar and Dvir (2007), Söderlund (2002, 2004 a, b)), by expanding the focus to journals "*outside the conventional project management publications*" that are "*likely to publish empirical and theoretical work on project management*". Söderlund (2011) notes that reviews of work published in the mainstream journals have been conducted by several authors and summarises the scope of their focus "*on narrow project management topics, such as risk management, project manager competencies, and planning techniques*".

To develop the focus on the identification of the key characteristics, Kolltviet et al. (2007) ask: *"Which perspectives do today's authors mostly use in the field of project management?"* (Kolltviet et al., 2007, page 3) and suggest: "*project management has to deal with an enormously broad range of issues: technology, organisation, strategy, finance, contracts, culture, planning, control, communication, environment, team working, etc."* (Kolltviet et al., 2007, page 3) which outlines the challenge of understanding the influence of issues on project performance and identifying the location of knowledge gaps across the multitude of relevant topics.

Comparison of Pinto (2002) and Bredillet (2007a) suggests that the demands being placed on the current structures of project management, from both project types as well as changing applications, are pushing the limits of practice and supporting research is unable to offer means of expanding the capabilities of project management.

This is reflected in project managements economic relevance, twenty one per cent of global gross domestic product has been argued to be *“gross capital development and managed as projects”* (Bredillet 2007a page 4; 2010c page 4), In some countries, particularly India and China, this is significantly higher (Bredillet, 2010c page 4; Anbari et al., 2008, page 1).

Recognising the multiple literature dimensions discussed above, and the numerous relevant articles, literature reviews are surprisingly limited. Lawrence and Scanlon (2007), after ten years of research, give an example: *“It would have been useful to the argument at this juncture to review a critical literature on the weaknesses of quantitative project management techniques”* (Lawrence and Scanlon, 2007, page 512), and refer to Galway (2004);”*Yet, as the author of a recent RAND Corporation study discovered, no such critical literature exists”* (Lawrence and Scanlon, 2007, page 512). The concern about the *“weaknesses of quantitative project management techniques”* Lawrence and Scanlon (2007, page 512) is consistent with the aim of this research to investigate project performance and suggests a further stage of narrowing the research focus on the underlying process rather than the technical content of specific projects.

This overview has highlighted some top level issues and challenges the view that immediate focus on narrow topics will result in well-structured global views. This suggests that an underlying issue is the need for research that examines the broad structures of project management as well as focusing on the emergence of tools and techniques, as identified in the research aim. Some of these topics are considered in more detail in the following sections.

2.3 Background context

The origin of academic interest in project management is traced to Gaddis (1959) who was “*probably the first one that truly pointed to the general management interest of project management*” (Söderlund 2004b, page 656). There is discussion that a ‘project’ and ‘project management’ are not the same thing, for example Munns and Bjeirmi (1996) regard a project “*to be the* *achievement of a specific objective, which involves a series of activities and tasks which consume resources. It has to be completed within a set specification, having definite start and end dates*" and project management as "*the process of controlling the achievement of the project objectives*". This thesis is primarily focused on the management process and the tools and techniques that support performance improvement.

The main period of contemporary development was in the aerospace and defense industry of the United States in the post 1950s period (Morris 2002, Johnson 2013). For example, Lyneis and Ford (2007) report Roberts (1964, 1974) publishing the first model of a project. Weaver (2008, page 1) dates the origin of critical path analysis to 1956. Notable exceptions are the Gantt chart, commonly dated to 1919, whose origins were in 1890 (Wilson 2003, page 431), and Adamiecki's Harmonogram from 1896 (Marsh, 1975). Some early projects and issues leading to the current perception of project management are described by Lenfle and Loch (2010). Hanif (2011, paragraph 3.8) provides a summary and time line of project management development, also see Weaver (website). Klimstra and Potts (1988) and Pinto (2002) summarise the period from the mid twentieth century and describe recent history. Hällgren and Maaninen-Olsson (2009) provide a brief discussion of the underlying philosophy and current state of the art of project management and highlight "*the shortcomings of contemporary project management's tools and methods*" (Hällgren and Maaninen-Olsson, 2009, page 64). Many of these tools and techniques emerged from a practice orientated role, which challenges the basis of research. Winter et al. (2006, section 3, pages 640-641) describes "*contemporary thinking in project management*", Rico (2010) discusses contemporary methods and their development.

Project management is developing as a key strategic role within business and industry; Klimstra and Potts (1988, page 38) *"expect project management to remain the most important way to manage the product or service development".* Söderlund (2004b, page, 655) argues it is at the core of understanding the modern firm. Eve suggests the world's most successful companies are *“adopting project management as a ‘‘way of working’’ rather than simply a methodology or tool set”* and that “*a robust project management core competency is a necessary condition for a company to maximize the affect of these methodologies”* (Eve, 2007, page 85). Pinto (2002) reviews the period since Klimstra and Potts (1988) and comments on the broadening scope (“*has branched out into business areas as diverse as insurance, banking and other service industries*” (Pinto, 2002, page 22)) and utilisation *(externally effective (fast to market) and internally efficient (doing more, faster, with less)* (Pinto, 2002, page 22)). The use of projects to support service applications is a significant example of the changing nature of project application, Artto et al. (2008, page 497) suggests: *“Project supplier firms are solution providers. A solution may consist of a core project delivery with specific service contents, and/or of separate service deliveries”.* This implies providers will have a much longer term relationship with their customers, potentially extended to meet the service lifecycle of the product. The “*project business*” view developed by Artto and Wikström (2005) is relevant in this context. This indicates a changing scope of the role of project management and consequently a challenge to locating a reference framework for research.

The scale of projects is also an increasing trend, projects valued at greater than US$1bn are considered routine and those exceeding US$100bn are becoming common, as indicated by Flyvbjerg (2014) citing the McKinsey Global Institute (2013) estimate that “*mega-projects”*, particularly in global infrastructure, account for US$3.4tn, or 4% of global gross domestic product. This adds a further dimension to the scope of the underlying problem and potential for research to contribute to improvement.

The contemporary role of project management is summarised:

> *“Therefore project management now has a very strategic role in industry and is not just being used as a means to mitigate corporate risk. This is an important distinction because project managers are now, more than ever, being looked to as the people who are going to*

> *implement the corporate strategies and objectives rather than just reporting status or disaster".*
>
> Kloppenborg and Opfer (2002, page 18)

A 'key characteristic' (Zheng et al. 2008) identified by Kloppenborg and Opfer (2002, page 18) is the role of the project manager as 'implementer' rather than 'reporter'. This can be considered in conjunction with the expansion into services (Artto et al. 2008) and the work of Winter et al. (2006, page 642) who identify five 'directions' of development, of which project management applied to new disciplines ("*Broader conceptualisation"*) and delivering results to stakeholders ("*Value*") are argued to be the most significant. "Value" is recognised in the broader economic context (Pitelis 2014, Foresight 2013) and project management is central: *"No longer just a sub-discipline of engineering, the management of projects – including programme management and portfolio management – is now the dominant model in many organisations for strategy implementation, business transformation, continuous improvement and new product development"* (Winter et al., 2006, page 638). This summarises the central strategic role that project management has developed in the contemporary management environment. It also identifies a further aspect of the research focus; 'programmes' and 'portfolios' can be argued to be collections of projects. This research will focus on single projects and 'tasks' which are the basic building blocks.

Yet, despite its developing strategic role and economic relevance, shortly after project managements emergence (Gaddis, 1959) the issue of project failure was recognised academically (Avots, 1969). This is reflected by other authors: Morris and Hough (1986, 1987) summarise 3,500 projects, and identify overruns between 40% and 200%; Shenhar and Dvir (2007, page 93) recognize that: *"most projects still fail and many projects do not accomplish their business results"* (although they add: "*This presents possibly a unique opportunity for substantial Improvement*"). The problem remains relevant; Gauthier and Ika (2012, page 5) identify multiple dimensions of performance failure; "*delays, cost overruns, underperformance in terms of quality, user satisfaction, and* *achievement of strategic or business objectives, as well as disappointment on the parts of stakeholders, all seem to have become the rule and not the exception in the contemporary reality of projects*". Flyvbjerg et al. (2003, chapter 1) identifies the "*mega-projects para*dox" in terms of performance summarises the perception of project failures or lack of performance and highlights the need for improvement.

It might be expected that performance would have improved in the 43 years between Avots (1969) and Gauthier and Ika (2012), particularly considering the volume of literature and multiple 'schools of thought' focusing on resolving this problem. Investigating why it has not, and offering improvement proposals is a relevant research topic. This provides motivation to investigate project performance by researching areas that target failure sources and detection techniques. But the dimensions of the subject provide a challenge to locating a research focus.

The track record of failure suggests that something is fundamentally wrong, illustrated by Söderlund (2011) which is sub-titled: *"Making sense of fifty years of project management research".* If, in 2011, it was still necessary to consider how to make sense of the collective background of project management research then there is clearly a fundamental issue with the subject's foundations, its structure and the basis on which useful development can be progressed. Lawrence and Scanlan (2007, page 512) take this further; *"According to Peter Morris, one of the UK's leading experts, project management is, 'a discipline that remains stuck in a 1960s time warp' "*[2]. Winter and Smith (2006, page 13) reinforces this:

> *"In essence, conventional project management theory remains wedded to the epistemological/ontological foundations of the 1950s/1960s, with its emphasis on machine-like conceptions of organisations and projects, and realist assumptions about 'organisations' and 'projects' as entities existing 'out there'*

[2] Winch and Pinto (2013) provide a summary of Professor Morris' contribution

independently of the people involved, (see for example, Packendorff, 1995)".

Winter and Smith (2006, page 13)

Hällgren and Maaninen-Olsson (2009, page 54) describe it as being *"aligned with the notion of explicit and mechanistic control, and is output-based"*. If projects are to continue to play a significant role in the development of society, their performance needs to improve. Continuing with the current levels of waste and failure is unacceptable. There is some hope; Anbari et al. (2008, page 1) observe that "*Project Management makes a significant contribution to value creation globally*" although they also argue that "*it is necessary for project management to develop as a rigorous academic field of study in management, so that the rapid economic development that is so dependent on project management can be underpinned by sound theory*". Koskella and Howell (2002, page 11) state: "*It is no exaggeration to claim that project management as a discipline is in crisis, and that a paradigm change, long overdue, has to be realized*", this suggests that researching the development of "*sound theory*" (Anbari et al. 2008, page 1) is necessary.

In order to locate research, the theoretical foundations of project management should be examined. Ahlemann et al. (2013) identify the search for methodological solutions, but recognise the problem project management research suffers from; they *"identify a lack of empirical and theoretical foundations as one cause of these deficiencies",* (Ahlemann et al., 2013, page 43). Morris (2000, page 2) suggests project management is "*insufficiently connected to the question of business success; and that its conceptual framework is inadequate to the job it should really be addressing"* and outlines the challenge:

"The challenge of research in project management today, I contend, is to build a broad, multi-industry, theoretically grounded, explanation of what is required to initiate and accomplish projects successfully. Research has a fundamental role to play in building this theoretical framework".

Morris (2000, page 23)

Resolving the underlying problem of the theoretical foundations of project management was previously examined by Betts and Lansley (1995, page 215) who suggest *"An obstacle to this happening appears to be the lack of an academic identity for project management".* Thirteen years later, Jugdev (2008, page 177) opened by suggesting "*Project management is in its infancy when it comes to developing a theoretical foundation*" and that "*Unless we develop a theoretical foundation, we run the risk of furthering the discipline in an atheoretical and ascientific way*". Bredillet suggests that it *"leads me to question the scientific field behind this discipline"* (Bredillet, 2008d, page 2). Bredillet (2008d to 2010b) develops the argument for developing the theoretical foundations of project management by suggesting that *"the importance of characterizing, defining, and understanding this field and its underlying strength, basis, and development is paramount."* (Bredillet, 2008d, page 2) and concludes that the project management "*field is still evolving in breadth and depth*" (Bredillet, 2008d, page 3), which provides a framework of the initial challenge to locate research.

However, progress has been made. Two years later Bredillet suggested project management is "*becoming more mature – although very dynamic – and focused around the role of projects in strategic issues*" (Bredillet, 2010a, page 4). Subsequently, Bredillet (2010c, page 4) reiterates the need "*for project management to develop as a rigorous academic field of study in management*". But the broad problem still remains; *"There is no consensus on any particular theory, though the research being carried out can be considered scientific in nature"* (Bredillet, 2010c, page 6). It can be concluded that there is a fundamental need to investigate the theoretical foundations of project management as a prerequisite to examining performance improvement.

To start to tackle the challenge presented by Morris (2000, page 23), the range of theoretical dimensions that influence project performance and the lifecycle processes required to deliver a project must be identified and examined with respect to their potential to positively influence project performance. Where it is identified that topics do not contribute positively to project performance, they need to be revised (or discarded). Alternative perspectives and new techniques, focused on the needs of contemporary project management, as identified by numerous authors, need to be investigated. Delivering the role of implementer (Kloppenborg and Opfer 2002) requires project managers to be proactive and forward looking and concerned about future events rather than just reactive and reviewing or reporting status. To achieve this, project managers will need predictive tools. An initial assessment of the functional role of project management tools and techniques might suggest that few, if any, are predictive. It is concluded that there is opportunity, in fact a need, to examine the foundations of project management and develop methodology to guide practitioners in assessment of detailed analysis and structure required to deliver improved project performance.

To structure a research focus to investigate the potential benefit of predictive tools indicates a need to investigate their development in the broader context of project management development, which, in turn, is based on its underlying theoretical foundations and its community paradigm (Kuhn 1996, page 176-181). What might be taken as the current description to a community paradigm is focused on the 'temporary organisation' and was introduced by Packendorff (1995). Yet Packendorff (2002) critiques its use which suggests it is an inappropriate term. Development in this area would support the view of Winter et al. (2006) that a focus on purpose would be relevant. In this case the view that projects exist in open systems (Smyth and Morris, 2007, page 423) and that performance is an emergent property can be discussed. This can be extended to investigate the view that project management is a sub-field of management (Söderlund, 2011) and that there is a case to argue for the location of management science in the design science philosophy (Simon 1996, Tranfield, 2002b, Cioffi, 2006, Ahlemann et al., 2013).

The research aim (stated in chapter one) defined the objective of investigating issues underlying project failure and identified the need to examine how tools and techniques to predict performance emerge from project managements theoretical foundations. The initial concern is to identify topics that define ‘project performance’ and if there are any conflicts with other project management topics (e.g. risk). The research aim identified a need to conduct research that focuses on detailed analysis and structure required to identify failure sources and detection techniques and develop methodology to guide practitioners to achieve improved project performance, which will be developed in subsequent chapters.

An immediate challenge is identifying relevant, high quality, literature, as it almost guarantees that some significant literature will have been missed. The challenge is recognised by Betts and Lansley (1995, page 215) who argue that articles “*do not appear to have employed the sources of data or produced the types of theoretical contribution that are usual in more established academic disciplines*”. Bredillet identifies the underlying problem; “*Yet in both the academic and the business world, the field of project management is not clearly established and defined*” (Bredillet, 2008d, page 3). This indicates a fundamental problem in identifying key characteristics of the community paradigm from which knowledge gaps and focused research can be located. This also suggests that examining the criteria that support project management being “*established and defined*” would provide a step towards the identification of a research focus.

2.4 Future Directions of Project Management Research

The context for the development of project management research is described by Bredillet (2007b page 3), who argues that “*the need is growing among the management research community and professional associations to clarify project management research trends*”. Various authors examine the development of project management research. Winter et al. (2006) is the most significant activity that focuses specifically on this topic. Literature review on project management research trends identified several papers and a range of topics, summarised in table one.

Table 1: Future directions of project management research

Author: / Topic	Project assumptions	Methodology	Paradigm	Conceptual base	Broadening scope	Specific 'research directions' described	Latest area of research discussed	Mismatch between 'promise' and 'actuality'	Schools of thought	Interface with other disciplines	Definition of a project	Definition of 'project management'	The discipline of Project Management	Temporary organisation	Bodies of Knowledge / Knowledge creation	Complexity	Project success	Project failure	Diversity of industries utilising project management
Crawford, Morris, Thomas, Winter (2006b)	✓																		
Morris, Crawford, Hodgson, Shepherd, Thomas (2006)	✓					✓	✓								✓				
Winter, Sandersen ,Elvin, Levene (2006)				✓	✓														
Atkinson ,Crawford, Ward (2006)				✓	✓			✓		✓			✓		✓				✓
Cicmil, Williams, Thomas, Hodgson (2006)		✓			✓	✓										✓		✓	
Maylor, Brady, Cooke-Davies, Hodgson (2006)				✓	✓		✓			✓	✓				✓				✓
Winter, Smith, Morris, Cicmil (2006)		✓	✓	✓	✓	✓		✓							✓				
Söderlund (2004a and b)					✓	✓		✓			✓						✓		
Mullaly and Thomas (2007)			✓			✓	✓						✓		✓				
Leybourne (2007)			✓		✓	✓	✓						✓				✓		
Geraldi et al. (2008)			✓										✓		✓				
Bredillet (2007a - 2008c)	✓				✓	✓	✓	✓	✓				✓		✓		✓		
Shenhar and Dvir (2007)			✓		✓	✓	✓	✓		✓	✓	✓	✓		✓			✓	✓
Söderlund (2004)					✓	✓	✓	✓	✓			✓		✓	✓		✓		
Pinto (2002)	✓				✓		✓												
Lundin and Söderholm (1995)			✓		✓	✓	✓				✓			✓	✓				
Midler (1995)		✓	✓		✓	✓													
Packendorff (1995)	✓	✓	✓		✓	✓	✓			✓	✓	✓	✓	✓	✓			✓	✓

A review of literature in table one suggests the significant research directions are:

1. Diversity and broadening scope of project management
2. Mismatch between the promise and actuality of project management
3. Project management paradigm, definitions, and its development as an academic discipline
4. Bodies of Knowledge / knowledge creation
5. Business – project success / failure / performance / evaluation
6. Complexity
7. Project management as a value creation process

Whilst the main theoretical issue is the development of the community paradigm (3), the primary practice issues are the broadening scope (1) and the need to deliver value (7), as these topics relate to purpose. Other topics relate to process. Process will follow purpose. Research topics that focus on traditional topics without considering these trends are unlikely to relate to the development of a community paradigm, and therefore, useful development of the subject. This illustrates the breadth of issues that can influence project management performance and consequently the potential to locate research.

2.5 Project management: 'Discipline' or 'Field of study'?

Establishing project management as a 'discipline' or 'field of study' defines a key characteristic that will set a direction for investigating performance and developing a research focus. Several questions are prompted to examine the difference between 'discipline' (e.g., does a 'discipline' have a formally recognised theoretical foundation?) and 'field of study' (does a 'field of study' have a loose structure, recognised as an area of interest?). Resolution is dependent on how project management is defined and the theoretical background that supports this i.e. the community paradigm. The challenge is summarised:

> *"In the case of PM, the field is more applied and interdisciplinary than other management disciplines so naturally it is more difficult to justify*

the field as a distinguishable academic discipline within the academic management community and more obstacles lie ahead".

Kwak and Anbari (2009, page 444)

One 'key characteristic' that is necessary for project management to be recognised as a discipline is its independence from any particular industrial sector. This position is clarified by Kozak-Holland who describes "*The world history of projects reveals that most projects, […] have strong similarities in terms of the phases or stages in the sequence of steps. They follow a method and have a set of requirements, designs, and constraints.*" (Kozak-Holland, 2011, page 41). The 'method' identified by Kozak-Holland aligns with the lifecycle model discussed by Morris. Besner and Hobbs (2008) surveyed 750 project management practitioners, they recognise commonality and also difference in the context of application. Crawford (2006a, page 175) also "*found variation in project management knowledge and practices between industries, countries and application areas*". This supports the view that there is industry specific knowledge and experience that is relevant to any particular project. This supports the argument for independence from any specific industrial application in order to develop the common topics and understand how difference needs to be recognised within the development of the discipline.

Closer examination of the subject's development may assist in positioning it and identifying the community paradigms, as discussed by Kuhn (1996). This is necessary to define a framework, or knowledge gap, in which useful research can be conducted.

Although there is no definitive answer to the 'discipline' or 'field of study' question, Morris (2013b, page 7) suggests its emergence as a discipline can be traced to the 1970s. There is clear intent that project management should be recognised as an independent discipline. Hambrick and Chen (2008) discuss the development of strategic management towards acceptance as an academic field. They argue that the identification of a distinct academic field is important, and even a pre-requisite to the definition of the community paradigm for that field, (Hambrick and Chen, 2008, page 34), and refer to Kuhn; *"Scientific* *communities can and should be isolated without prior recourse to paradigms; the latter can then be discovered by scrutinizing the behaviour of a given community's members"* Kuhn (1996, page 176). In this respect a clear scientific community can be identified as many of the authors cited here specialise in project management research and there is a clearly defined practitioner role of 'project manager' in many industrial sectors supported by relevant professional bodies. Despite the clear existence of the necessary criteria for the emergence of a community, its development as a distinct discipline with a recognisable community paradigm has not been achieved. White and Fortune illustrate the problem, whilst arguing that *"Project management is now well developed and well accepted as a domain for the exercise of professional expertise and as an area for academic research and discourse"* (White and Fortune, 2002, page 1). They also point out "*project management remains a highly problematical endeavour. A great many projects exceed their budgets, run late or fail to meet their objectives"* (White and Fortune, 2002, page 1). Ten years later, Gauthier and Ika (2012, page 5) suggest "*project management is emerging as a true scientific discipline in its own right"*. If the view suggested earlier that there is no definitive answer to the 'discipline / field of study' question is correct, it might be accepted that the process is under way.

This challenges the potential to identify the community paradigm and subsequently 'knowledge gaps' as the underlying framework is undefined. Therefore the boundaries of existing knowledge are not clear to allow the 'gaps' to be clearly identified. Examination of more specific topics will examine whether this issue can be resolved, or if the same lack of existing knowledge exists elsewhere.

This problem exists because of the lack of community paradigm – if one was accepted then it would be clear where the subject was located. 'Gap-spotting' will not progress development towards a community paradigm.

2.6 Theoretical foundation and paradigm of project management

The investigation has identified a broad literature base and that there are directions to research, but that project management is not fully identified as a scientific discipline. This leads to a lack of support of developing the research focus. This section investigates the current theoretical foundation and community paradigm. Identification of these key characteristics follows the philosophy of Kuhn (1996).

The objective of examining the community paradigm is to identify the baseline for the research focus and question to be developed. The problem of project managements theoretical foundation is described by Kwak and Anbari (2009) who comment on Themistocleous and Wearne (2000); *"that in terms of theory building and the theoretical basis of project management, there was still a large room for improvement" (*Kwak and Anbari 2009, page 436). This presents an immediate problem for the identification of the community paradigm. As discussed in chapter two, Kuhn suggests the paradigms of a mature scientific community can be "*determined with relative ease*" (Kuhn 1996, page 43), which would readily lead to the identification of anomalies and subsequently clear knowledge gaps and defined research issues. This is challenged by the previous discussion and further examination of the theoretical foundations and paradigm is needed.

Calls for the theoretical development of project management are not new; Betts and Lansley (1995, page 215) argue "*that the next stage in the development of an academic discipline is the building and testing of models such that a theory of project management may emerge*". Williams (1999) discusses the need for new paradigms. Söderlund (2004a, page 184) cites Shenhar and Dvir (1996, page 608) who stated that most research on project management ''*suffers from a scanty theoretical basis and lack of concepts*''.

Koskela and Howell (2002, page 1), states Kloppenborg and Opfer (2002) do not report anything on the theory of project management. This suggests the period prior to year 2000 has no significant theoretical literature. Koskela and

Howell (2002 page 12) further suggest: "*The present evidence is strong enough for the claim that a paradigmatic transformation of the discipline of project management is needed*". Pinto (2002, page 22) argues that *"a number of technological and behavioural developments have occurred that make it necessary to reconsider the current state of the discipline".* Other authors have identified the same problem: Anagnostopoulos (2004), Cooke-Davies et al. (2007, page 50) notes that *"The discussion, however, has been somewhat hindered because the issue of theoretical foundations in project management research has been a central point of debate among both practitioner and scholarly communities for quite some time".*

Several theoretical perspectives are identified from articles citing Betts and Lansley (1995); Pollack (2007) provides a broad examination, Littau et al. (2010) study stakeholder theory, Jamali and Hashmi (2010) examine projects in relation to "*the theory of inventive problem solving*" (acronym; 'TRIZ'; from its Russian origins (Dew, 2006), a Scopus search (3rd November 2014) returned 3,058 results). Hanisch and Wald (2012) review the use of contingency theory. These different views suggest that no agreed theoretical base for project management has emerged during more than fifty years of documented research, summarised by Smyth and Morris (2007, page 423); "*A unified theory of PM does not exist*".

It would appear that little progress has been made as, more recently, Bredillet (2010c, page 6) discusses the state of the theoretical basis of project management and identifies a range of issues and suggests: *"The current phase of development of the field is characterised by several incompatible and incomplete theories and perspectives"* (see, for instance, "From the Editor", Project Management Journal, volume 38 issue 2 to volume 39 issue 3). Bredillet (2010c, page 6) argues *"that the field is in a preparadigmatic phase according to Kuhn's sense (1983)".*

More recently Gauthier and Ika (2012, page 5) also recognise issues with the theoretical foundations and suggest "*some authors have singled out certain scant or fragmented theoretical background and, not surprisingly, one of the* *responses to this criticism has been to investigate the theoretical underpinnings of the project management field*". The problem remains current; Ahlemann et al. (2013, page 43) "*identify a lack of empirical and theoretical foundations*" and clarify; *"….one would have expected PM to have reached a high level of expertise and maturity in delivering methods to solve practical problems. Surprisingly, the opposite seems to be the case: Numerous studies report on serious problems related to proposed PM methods"* (Ahlemann et al., 2013, page 43).

The wide range of topics identified in the literature, many of which appear to be relevant to the overall problem of the theoretical foundation of project management, suggest the "*absence of a paradigm or some candidate for paradigm*" (Kuhn 1996, page 15). Betts and Lansley (1995) and Crawford et al. (2006a) identified the issues of literature quality and the potential transitory nature of topics within the literature. This may be symptomatic of the pre-paradigmatic state of the discipline, as described by Kuhn.

This identifies a significant problem from the research perspective. The lack of theoretical basis or community paradigm means that there is no framework in which any particular issue, such as project performance, can be located to allow knowledge gaps to be identified. Given this position, it is necessary to further investigate this issue and its relationship to the broader context of the research framework required to define a research focus, in order to identify key characteristics and some structure to locate the research focus. This is developed in chapter four.

The 'temporary/unique' paradigm

A further topic that needs to be examined is the common approach to categorising projects as 'temporary / unique'; this presents a description widely used in the absence of a formally accepted community paradigm. Packendorff (1995) introduced the concept of projects as temporary organisations. A search of articles published prior to 1995 showed little use of the term, and only occasional reference in the context of 'temporary organisation'. For example, Baccarini (1996, page 202) uses the term once, but with a different emphasis to many of the post 1995 articles. The use of the term is put in to a form of context by Turner:

> *"Other people say that all organizations are temporary; none last for ever. The oldest organization that I know about is the Roman Catholic Church which is 2000 years old. That is temporary on some time scales."*
>
> Turner (2006a, page 1)

Although the context of '*temporary*' is set by Turner (2006a, page 1), in practice, it ceases to have relevant meaning in the context of project organisations and the working environment. The concept is further examined by Turner and Műller (2003) and Braun et al. (2013) discusses behaviours in temporary organisations.

'Temporary' also has implications of a lack of substance, which many projects clearly are not. The concept of 'temporary' is also an external view of the organisation. Project organisations exist to deliver their objectives. They do not disband until the objectives are complete (or agreed to be changed, if the project is terminated early). From within the organisation there is nothing 'temporary' about the motivation to deliver the project objectives. Use of the 'temporary' term can take the focus away from the most important aspects of the projects existence. 'Temporary' provides a characterisation that describes the consequence of the activity, rather than focusing on characterising the purpose or function of the activity. This might be argued by considering that the project organisation may have a relatively short lifecycle, and therefore be regarded as 'temporary', but the objectives of the project are normally expected to last longer, and might be regarded as more permanent. For example, the organisation that built the pyramids is long gone. The pyramids have been around for 4,500 years and are unlikely to be dismantled (or erode completely away) any time soon.

Söderlund (2004b) recognises Packendorff (1995) but suggests that the concept is "*somewhat dated and does not acknowledge the development and* *broadening of the scope of project management research*". In fact Packendorff, who introduced the 'Temporary' terminology in 1995 has challenged its relevance (Packendorff, 2002) and has criticised it, albeit from the perspective of the individual actor. Packendorff (2002) discusses implications of '*projectisation*' and the '*temporary society*' and examines whether the concept is delivering to its expectations. If the author who introduced 'temporary' in 1995 is criticising it in 2002, then an alternative is needed. Part of the problem might be the focus of academic research; Morris provides an academic research perspective:

> *"Many academic researchers are primarily interested in projects as examples of temporary organisations, rather than in questions about building a discipline for the delivery of goals".*
>
> Morris (2013b, page 6)

The delivery of goals is the reason for a projects existence, so should be the focus of its structure and process.

One approach to considering the relevance of 'temporary' and 'unique' to the definition of a project might be to compare two industries, one which has a short project lifecycle, such as the film industry, (Ludwin, 2003) where organisations might exist for one year, and another that has a longer project lifecycle, such as the aerospace industry where projects can last over decades (e.g. The Boeing 747 originated in the mid-1960s, the 747-8 was introduced in 2010 and is likely to be in service till at least 2050, a project lifecycle exceeding 80 years). A further consideration is 'service projects'. The objective of 'service' projects is to maintain the project activity, although within a changing organisation, to support the product throughout its service life, for example Rolls-Royce's 'TotalCare®'[3] results in 50% of revenues being derived from servicing (Pitelis, 2014, page 76).

The 'temporary' label has been extended to describe the organisation, although there is recognition of different perspectives;

[3] http://www.rolls-royce.com/civil/services/totalcare/

> *“The ‘temporary organisation’ characteristic of projects is only one theoretically relevant aspect. There are many differences including those in Table 1* [of Reich et al., 2013], *which can form the basis for project based theory.”*
>
> Reich et al. (2013, page 940)

The academic focus on project teams as ’temporary organisations’ has not led to any significant performance improvement. In fact this has led to an academic focus on the organisation rather than the purpose for which the project was initially established. Morris (2013a, page 116) argues that “*focusing on this as the principle criterion that characterises the domain of enquiry is wrong*”.

Yet, nearly twenty years on, the ‘*temporary organisation*’ terminology continues to be used as the point of departure, e.g. Florical et al. (2014). Despite this, it is concluded that ‘temporary’ cannot be used in the context of defining research issues.

‘Temporary’ is often linked with ‘unique’ in many articles (e.g. Stanleigh 1999; Turner and Müller, 2003; Uppal, 2009; Hanisch and Wald, 2011) and definitions adopt this approach. Anagnostopoulos (2004) discusses the context for ‘uniqueness’, which is relevant in the argument of identifying characteristics that differentiate projects from other activities. The term does not directly define the differentiating function of a project, as many common tools and techniques are applied. The use of the term is summarised:

> *“If projects do not possess the quality of uniqueness, then they cannot be differentiated from operations and can lead to the erroneous conclusion that everything can be described as being a project. On the other hand, if they do not have some minimal common features, it is difficult to foresee how PM can be established as an autonomous scientific field”.*
>
> Anagnostopoulos (2004, page 252)

This problem is also considered by Hällgren and Maaninen-Olsson (2009).The identification of projects as “unique” provides a different perspective:

> *"Although projects are by nature considered unique (Nicholas, 2001), during execution there are also repetitive tasks. These repetitive tasks can be managed through the use of project management methods and tools, which imply that the execution of a project can be achieved on the basis of a general structure (Nicholas, 2001). The general structure (the plan) assumes that the tasks can be predetermined."*
>
> Hällgren and Maaninen-Olsson (2009, page 55)

'Temporary' and 'unique' might be taken as being the closest to a current project management paradigm, but they are not specific terms that can be described as a paradigm.

These terms are used in publications such as the bodies of knowledge (e.g. PMBok, APMBoK), which are widely used as guidance by many project managers; but do not represent an appropriate paradigm in the contemporary context. Therefore, it is not a sound foundation for projects to be conducted. This is a major issue given the wide use and fundamental application of the terminology. Thus, these terms should be discarded in the context of a project management community paradigm and challenging their relevance as the basis of the community paradigm offers significant potential for theoretical development.

2.7 Bodies of Knowledge and process models

The focus in this section is to examine the role of the 'bodies of knowledge' published by the professional associations and some national organisations. These 'bodies of knowledge' define "*the elements of project management in which competent project management professional should be knowledgeable*" (Morris et al., 2000, page 155). It is appropriate to examine their relevance to developing methodology to guide practitioners and the identification of issues underlying project failure, as discussed in the research aim.

The underlying theoretical focus, or paradigms, of the bodies of knowledge need to be considered. In this respect "*The Body of Knowledge thus reflects the ontology of the profession: the set of words, relationships and meanings that describe the philosophy of project management*" (Morris et al., 2000, page 156).

There are different paradigms underlying the bodies of knowledge, the Project Management Institutes (PMI) "*Project Management Body of Knowledge" (PMBoK) focuses on project process lifecycle and "stage-gate process now commonly adopted as good governance practice*" (Morris et al., 2006), whereas, the APMBoK focuses on '*management of projects*' and "*issues that need managing as the product evolves through its development lifecycle*" (Morris et al., 2006, page 717). Citing Koskella and Howell (2002), Jugdev (2008, page 185) suggests "*that the Project Management Body of Knowledge Guide, for example, involves an 'implicit' theory streaming from operations management but no mention is made of explicit theory*". If one of the key guides does not identify its theoretical foundations, there needs to be more work to develop an appropriate theory.

The 'bodies of knowledge' provide practitioner 'prescriptive' advice. Whilst this might be described as prescriptive theory, they are largely derived from practice experience (Hanisch and Wald, 2011, page 4). The review of journal coverage relating to the bodies of knowledge by Themistocleous and Wearne (2000) showed a wide range of interest, on both topics and different coverage by different journals.

However, in the context of utilising the bodies of knowledge as a basis of this research, the questions to ask are: What are the 'underlying assumptions' of the bodies of knowledge? And; do they support the research activity? This leads to several lines of research being proposed, centring around the development of project management as a professional discipline and how the bodies of knowledge contribute to that aim. The need for this work, in relation to development of the bodies of knowledge is identified by Morris et al. (2006):

> *"If they remain unchallenged the discipline (the profession) risks being defined by models which ignore areas that are critical to*

> *achieving satisfactory outcomes. As a result, project management may at best sometimes be ineffective, or at worst downright wrong."*
>
> Morris et al. (2006, page 717)

This concern was reinforced in the 'rethinking project management' investigation carried out by Winter et al. (2006). Various points of criticism of the bodies of knowledge are raised which challenges their relevance as the basis of research;

> *"In fact, the PMBoK Guide and many of PMI's standards generally do not, in the Network's view, adequately reflect the research literature, either in scope of topics covered or in substantive detail rendered".*
>
> Morris et al. (2006, page 717)

The challenge is to establish the appropriateness of the bodies of knowledge as a basis for research rather than practice. The simple fact that these are 'guides' and the label 'body of knowledge' suggests a collection of topics rather than a coherent theoretical foundation.

> *"Even though the body of knowledge established in the project management area is "rich and helpful" (Shenhar & Divr, 2007a), it still takes on a rather practical view and often does not address the deeper issues and interdependencies between factors that influence project work".*
>
> Hanisch and Wald (2011, page 5)

This suggests the key characteristic of the various bodies of knowledge is that of practice orientation and focus on guidance to practitioners, based experience rather than rigorous research. This does not support the view that the bodies of knowledge provide a significant foundation to locate research.

It can be summarised that as a point of departure for academic research, the role of bodies of knowledge is limited. It can only be concluded that the project management bodies of knowledge are practice focused and do not align to theoretical foundations and therefore are not useful for fundamental research.

They will not be used to support the development of the research issue / question.

A further consideration is process models (Garel, 2013), such as ‘PRINCE2’ and Microsoft ‘Project’ and how useful these are as points of departure. These are primarily aimed at practitioners, typically focus on the traditional topics of scheduling and status reporting. The position is summarised by Winter et al. (2006);

> *“Current industry offerings however, in training and development, tend to centre on particular products – such as PRINCE2* [PRINCE2, 2005] *and MSP –* [MSP, 2003] *many of which embody some or all of the mainstream ideas in project management. Experience shows however that it is people who deliver successful projects, not methods and tools, and it is people’s ability to engage intelligently with the complexity of projects, that is central to the successful management of projects”.*
>
> Winter et al. (2006, page 646)

Similarly to the Bodies of Knowledge, process models do not provide the underlying theoretical foundation required for research. This does not support the identification of knowledge gaps that allow fundamental research to be defined.

2.8 Schools of thought

Whilst the bodies of knowledge may have their limitations in respect to research, a broader view needs to be taken to identify the theoretical foundations of the subject. Several authors examine the different perspectives and present discussion on ‘Schools of Thought’ as a description of a particular philosophical perspective. These ‘schools’ can be considered to represent the assumptions underlying the domain. The challenge is that Alvesson and Sandberg (2011) implies assumptions underlying a single domain, the multiple schools of thought identified in this section suggest multiple domains.

The most recognised school of thought is the 'Scandinavian school' which can be traced to publication of the "*Scandinavian Journal of Management*" (1995 issue 4). This was effectively the first 'school of thought', introduced the concept of the 'temporary organisation' (discussed in section 3.5). This philosophy continues to exert direct influence by the number of citing's identified in a Scopus search (Table two).

Table 2: Scandinavian Journal of Management 1995 Vol. 11 Issue 4: Citing's

Scandinavian Journal of Management 11 (4) - 1995			
Author(s)	Title	Cited since 1995	Cited during 2014 (January to November)
Kreiner, K.	In search of relevance: Project management in drifting environments	70	2
Lundin, R.A., Söderholm, A.	A theory of the temporary organization	241	20 (+1 dated 2015)
Løwendahl, B.R.	Organizing the Lillehammer Olympic Winter games	17	1
Packendorff, J.	Inquiring into the temporary organization: New directions for project management research	147	16 (+1 dated 2015)
Hellgren, B., Stjernberg, T.	Design and implementation in major investments - A project network approach	51	1
Midler, C.	"Projectification" of the firm: The Renault case	114	15
Schofield, J., Wilson, D.C.	The role of capital investment project teams in organisational learning	2	0
Kadefors, A.	Institutions in building projects: Implications for flexibility and change	47	4
Ekstedt, E., Wirdenius, H.	Renewal projects: Sender target and receiver competence in ABB "T50" and Skanska "3T"	5	1
Lundin, R.A.	Editorial: Temporary organizations and project management	9	0
	Total	703	62

The 'Scandinavian school' is not the only perspective applied to project management. Jugdev (2008, section 5) discusses schools of thought in management theory and identifies the 11 schools of thought identified by Koontz (1980), and then developed the five dominant theories in management (Organisational theory, Organisational learning, Strategic management, Transaction cost theory and Agency theory (Gonzalez et al., 2001)). From this Jugdev (2008) proposes "*eight factors which follow and are worth considering in* *the context of project management*". Jugdev (2008) then discusses the project management schools of thought presented by Söderlund (2002) and analyses them in relation to Koontz (1980) and Gonzalez et al. (2001). These multiple 'schools of thought' support the pre-paradigmatic position (in the context of Kuhn) suggested by Bredillet (2008; 2010b). Other authors take a similar view:

- Kolltveit et al. (2007, Table 1): Six project perspectives
- Packendorff (1995): Seven schools of thought
- Söderlund (2011, page 166, table 2): Seven schools
- Winter and Szczepanek (2009): 'images of projects'
- Hughes et al. (2004): Several factors at the beginning of the project
- Anbari et al. (2008): Nine Schools of Thought

Bredillet calls for project management to be recognised as an academic field, maps out research trends and discusses project management as an academic discipline. In a series of six editorials, Bredillet (2007a to 2008c), explores research in Project Management "*in order to draw a mapping of the researches conducted in the field of project management and their main characteristics*" leading to the identification of nine schools of thought.

Table three identifies the different schools of thought proposed by various authors and attempts to cross reference them to examine how many different schools are being proposed. The table suggests that twenty three schools could exist, although this may not be an exhaustive examination. Even if it is accepted that project management may operate in multiple dimensions and benefits from different perspectives, it is also challenging to consider twenty three different ones. Additionally, there is no immediate correlation identifiable across the schools of thought. This range of different perspectives that are presented to form the foundations of the subject illustrates the "*pre-paradigm*" nature of project management as suggested by Bredillet (2010c) and discussed previously. Work to develop a more coherent understanding of these different perspectives may allow a common area to be established which may support the progress towards "*normal science*" (Kuhn 1996).

This is central to the argument of whether project management can be a mature discipline. If Bredillet (2007b – 2008c) identifies nine schools of thought, along with the other authors summarised in table three, it suggests there is no clear framework, therefore it can only be concluded that the subject is 'pre-paradigm'. To develop towards a mature discipline the challenge is to examine if the multiple domains identified by the various schools of thought can be reconciled to allow underlying assumptions to be identified and formed into a coherent community paradigm.

Table 3: Alignment of different schools of thought

School	Bredillet (2008)	Betts & Lansley (1995) (Project subjects)	Jugdev (2008)	Kolltveit et al (2007)	Packendorff (1995)	Söderlund (2011)	Winter & Szczepanek (2009)
	Behaviour	Human Factors			The human side of project management: control, structure and leadership	Behaviour School	Projects as Social Processes
	Governance			Leadership perspective		Governance School	Projects as Political Processes
	Optimisation					Optimisation School	
	Contingency		Contingency Approach			Contingency School	
		Project organisation	Organisational learning				Project as Temporary Organisations
		Project planning			The core of project management: planning the project		
				Task perspective			
			Transaction cost theory	Transaction cost perspective			
			Resources & Capabilities theory				
			Institutional theory and resources dependency theory				
			Population ecology (including organisation change)				Projects as Change Processes
		Project Start up				Factor School	
		Project procurements		System perspective			Projects as Intervention Processes
	Modelling	Conceptual models					Projects as Development Processes
	Success			Stakeholder perspective			
	Decision	Project performance		Business by project perspective	The performance of project management: goal-fulfilment and evaluation	Relationship School	
					Project management is seen as a general theory		
	Process	Project environment	Strategic management			Decision School	
		Project information	Agency theory		Abundance of normative advice despite lack of empirical evidence		
					Projects are seen as tools, not as organisations		
		Risk management					
		Innovation					
	Marketing						

The various schools of thought identify multiple perspectives, most of which have a relationship to project performance. Whilst clear gaps exist between many of the topics raised by the authors who discuss “schools of thought”, it is not clear what the foundations of any two topics are and, therefore, direct comparison is difficult from an ontological and epistemological position. The gaps between the topics show significant ‘space’ which is indicative of the problem of identifying focused research issues. This needs to be examined at a more fundamental level to determine a common basis on which to define a research focus.

Table three shows the range of Schools of Thought. It could be argued that this clearly shows ‘gaps’ but does not identify how any two topics are related. It does identify a lack of consistency across different perspectives.

2.9 General issues influencing project performance

This section examines literature that identifies numerous general issues across project management that influence project performance. Articles often focus on specific issues to identify the context of failure or low performance. They will be summarised here to examine the view that these issues can generally be linked back to the lack of overall structure.

There are three perspectives that have a major influence on the project, the business, the customer and the technology, (Berkun, 2008, page 48 – 56). This view allows the major relationships in the broad project environment to be identified. In addition, the global environment in which the project operates is important (Fortune and White, 2006). These views should be combined to consider the management and external environments that the project organisation operates within. This extended view is shown in figure 3. This approach is based around a single project model, and it is recognised that multiple projects would require further development of the model.

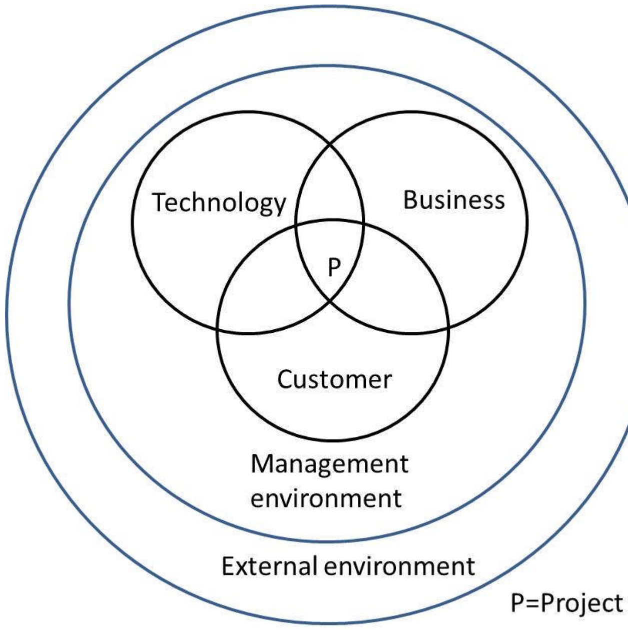


Figure 3: Project perspectives

As well as identifying the position of the project (P, in figure 3) within the 'global' environment, figure 3 also shows that other significant aspects influence the overall delivery of the project objectives. Any one of the Business, Customer, Technology or Environment can influence the progress of the project. As well as the relationship with the project, the other aspects also have relationships with each other and these can influence the progress of the project. If the project is to exist as an identifiable entity within the environment of figure 3, then its definition and functions and how it relates to the other aspects of its environment are important. This also illustrates the 'open systems' nature of projects (Smyth and Morris, 2007) that the project interacts with business technology, customer and the broader environment.

Söderholm (2008) discusses the projects interface with its environment and focuses on the management of unexpected events. Considering the overall project environment, Söderlund (2011) identifies 48 different criteria that could be used to identify knowledge gaps and generate research questions. How these criteria tackle fundamental issues would need to be further examined.

This group of issues considers those aspects associated with the broader environment of project activity, and those areas that might be considered generic to the broad operation of projects.

If the activities occur at a rate faster than the tools and techniques can monitor and analyse, then the project cannot be in control. Investigating this relationship and areas of focused research forms the basic objective of the work investigated in this thesis.

This challenges understanding of the location of project management within the broad framework and relates closely to its academic positioning:

- What differentiates project work from other activities? Why is it important?
- The relationship between project and customer
- The use of technology on projects
- Functions of a project and project management
- Relationship to project performance

From the perspective of research aimed at improving project performance, the task is to examine how each function relates to and supports the delivery performance of the project. From this analysis is should be possible to identify characteristics that can lead to failures in project performance. These characteristics can then be examined in the context if developing a research focus and research question.

2.10 Performance in industrial sectors

One of the arguments supporting the lack of theoretical foundation in project management is that it developed from industrial practice (Hanisch and Wald, 2011). Consequently, there is potential to develop research issues by examining the industrial context. To provide context, Morris, (2000, page 9) asks; "*What contribution has project management made to business performance?"*

How does the application of PM in industry support delivery of project objectives? How is project performance achieved and measured in industry? Is PM application carried out with a common set of tools and techniques? Performance is typically measured by indicators, such as 'key performance indicators' or 'performance measurement systems' (Haponava and Al-Jibouri, 2012).

It could be argued that the alignment of project management to any given industrial sector immediately assumes a relationship to the interests of the sector. Many articles (possibly the majority) are located in an industrial context, particularly IT and construction.

Considering the practice environment, a range of industrial sectors can be identified. Peippo-Lavikka et al. (2011) drew on 2,354 articles from 564 journals, to analyse the theoretical context of project management in nine different industrial sectors and a general engineering 'catch all' sector. Additionally, Cooke-Davies and Arzymanowc (2003) add 'defence'. Transport and electronics can also be added (Morris 2000). This resulted in a total of 13 sectors being examined. Morris et al. (2000, figures 2 and 3) identify multiple issues across multiple industrial sectors – indicating that the same basic issues are present (to a greater or lesser degree). This suggests that the resolution of issues should be considered independently of the industrial application.

One of the largest industrial sectors is construction, building and civil engineering, suggested by Crawford et al. (2006) as being potentially dominant. Construction represented the major sector. Crawford et al. (2006a) raised concern of the potential dominance of the construction industry and the "*associated risk that research conclusions may be unquestioningly and invalidly transferred between industry sectors"* (Crawford et al. 2006a, page 176). This was supported by Betts and Lansley (1995), Themistocleous and Wearne (2000) and Evaristo and van Fenema (1999), who pointed out that *"the current knowledge based on the management of projects emanates from large capital* *construction projects responsible for only 10% of the projects".* Citing Liu and Walker (1998), Cheung et al. (2013) position their research by arguing;

> *"Project performance is always one of the key concerns of construction project managers. It is often regarded as the critical indicator to measure the success of construction organization".*
>
> Cheung et al. (2013, page 941)

Whilst other sectors will have their specific knowledge to contribute to the broad theoretical development, that construction provides a significant input to the knowledge base indicates the commonality of the *"core set of concepts that most projects share"* (Kozak-Holland, 2011, page 41).

The second major sector using project management is Software, Information Technology, Telecom and Computers including hardware and software. Whilst Crawford et al. (2006a) raised concerns about potential dominance of the construction sector, White and Fortune (2002) identify dominance of the Information Technology industry. Keil and Mähring (2010) focus on Information Technology projects, but identify the issue of projects escalating resource consumption and failing to deliver.

> *"Large IT* [Information Technology] *projects can become the business equivalent of what astrophysicists know as black holes, absorbing large quantities of matter and energy. Resources continue to get sucked in, but little or nothing of value ever emerges."*
>
> Keil and Mähring (2010, page 6)

Extending the 'black hole' analogy, it might be asked 'Where is the project management equivalent of the 'event horizon'? (The 'event horizon' is the point at which escape from the black hole becomes impossible). The equivalent being the point at which the project becomes irretrievable. Why does this happen? What is the impact on project performance? Why are issues not identified and corrected earlier?

Keil and Mährings (2010) discussion on projects becoming 'black holes' observe; *"projects don't become black holes overnight. They get there one day* *at a time through a process known as escalating commitment to a failing course of action"* In this respect project performance is an emergent property, which would align with the suggested project description. Coulon et al. (2013) examine unexpected events in IT projects. Identifying unexpected events or the early stages of deviation from plan to allow correction to be applied could be relevant to improving project performance. Detecting problems within a project prior to them becoming a 'black hole', might allow correction to be applied. This would require initial action at an early stage in the project lifecycle and ongoing review.

A different perspective is introduced by Bannerman (2013) who introduces a 'capability' perspective and argues that performance emerges from the conflict between the 'organisational learning' processes that positively work towards efficient performance and the 'liabilities' that have a negative effect on performance.

One of the traditional areas is space, aerospace and aircraft engineering. In fact Morris (2002) suggests that the origin of modern project management partially occurred in the aerospace and defence projects in the United States during the 1950s. Although, an imbalance is shown by Betts and Lansley (1995) who identified only two papers related to the aerospace industry. More recent literature addresses this; Concorde and the Giotto satellite projects are compared (Jørgensen 1994). Price et al. (2006) describes the challenges of aircraft design, and the use of systems engineering. For example, most aerospace projects are multinational (e.g. Eurofighter, F-35 Joint Strike Fighter). Boeing has an international manufacturing element for the 787. Airbus sources materials internationally and manufactures across Europe and China (a final assembly line for the A319 and A320 is located at Tianjin, with an additional final assembly line for the A319 / A320 and A321 being constructed in the USA). Altfeld (2010) reviews the processes associated with the development of complex aerospace projects, focusing on the Airbus A380. Despite the international nature of aerospace projects, and the leading position of the US aerospace industry, Parsons (2006) suggests that NASA does not have a measure for rating interim project performance. This is either a major process failure, which could be considered a knowledge gap, or is a problem that is just too complex to achieve within the current state of the art. This suggests that investigating interim, or early stage, performance measures might be useful.

Another one of the traditional areas is defence. Johnson (2013) summarises several case studies of projects over the period from the late 1930s through to the 1960s and their impact on subsequent project management development. Tishler et al. (1996) summarises Morris and Hough (1987) and focuses on the low levels of performance of defence projects. Matta and Ashkena (2003) comment on project success and Lawrence and Scanlan, (2007) review aerospace and defence industry performance;

> *"It appears that when major aerospace and defence prime companies undertake large engineering projects the associated programmes invariably run over cost and over time."*
>
> Lawrence and Scanlan, (2007, page 510)

Chemical Systems, Chemical Engineering, and Oil and Gas: Dougherty and Dunne (2012) discuss the development of chemical compounds. Given the levels of risk taken by the Oil and Gas industry, particularly in terms of exploration and locating energy reserves, a major emphasis is placed on their project management techniques. This extends to the power, energy production, and energy systems and electronics sectors.

To illustrate the broadening conceptualisation (as concluded by Winter et al., 2006), project management has developed with increased interest in the environmental and sustainability sector, healthcare, biotechnology and pharmaceutical industries.

In the transport sector, for example, high speed rail generates substantial projects in all dimensions of value, complexity and need for detail management.

General Management and Business provides a 'catch all' sector for other application of project management. The industrial performance investigation has identified thirteen sectors in which there is a clear application of project management. Whilst concerns have been raised (Crawford et al., 2006a) about the dominance of construction, this review of industrial sectors does show other active areas.

2.11 Project performance

Morris (2013b, page 6) proposes that "*enhancing value*" should be a key characteristic of project management. Bredillet (2007b, page 3) identifies a need to develop "*competencies as sources of performance improvement and value creation*". This is based on a view that the purpose of a project is achieving its goals as the basis of delivering value (Winter et al., 2006). To support value creation by performance improvement, it is necessary to know what defines performance, and how its delivery is analysed.

Mir and Pinnington (2014) explore the relationship between project success and project performance. Haponava and Al-Jibouri (2012) consider the measurement of project performance by key performance indicators, but suggest; *"most of the existing KPIs are lagging by nature and, hence, are of little use for control purposes"* (Haponava and Al-Jibouri, 2012, page 149). This concern with 'key performance indicators' suggests that their metrics can only be determined post activity, indicating how well something was done. This does not help improve performance of the project during its lifecycle. The best opportunity is to apply KPI's to the outcome and 'lesson learnt' for application to future projects. However, the conclusions of Haponava and Al-Jibouri (2012) provides some direction including a discussion on what to control, how to control and the ability to take action as well as suggesting a focus on process performance rather than organisation performance.

Although focusing on information technology, Bannerman (2013) examines performance from 'Factor', 'Process' and 'Capability' perspectives and notes: "*Each of these research approaches has pointed to key antecedent variables that have been found to impact project performance in practice*" (Bannerman, 2013, page 4325). Developing a focus on '*antecedent variables*' rather than lagging KPI's would require assessment of problems 'before the event' rather than the traditional retrospective analysis. This might offer an opportunity to address issues before they become problems that influence performance.

This suggests a useful research focus would be on the project process and understanding the key characteristics of the process, and from a performance improvement perspective, those that enhance performance, or at least, reduce the potential of performance failures. Further, activities that provide performance prediction would be beneficial.

2.12 Discussion

The primary purpose of literature review is to identify where there is a clearly definable 'knowledge gap' that leads to a focused research issue to address the research aim. The review of the theoretical foundations of project management has identified a clear lack of theory, the basic problem of which is summarised;

> *"Since theory helps to direct researchers into productive lines of inquiry, the absence of explicit theory hampers the pursuit of programmatic research and the development of a cumulative tradition in the advancement of knowledge".*
>
> Sauer and Reich (2007, page 1)

This can be focused on the lack of a community paradigm that prevents 'normal science' (in the sense of Kuhn 1996) being applied. Knowledge gaps within the established framework of project process do not challenge the fundamental problem of how to deliver performance improvement. Therefore, identifying and filling a knowledge gap would not lead to an opportunity to deliver improved performance. It does not ask; what is being done differently in order to lead to improved performance? It asks; how do we keep doing the same thing and expect a different result. Applying the same tools and techniques to projects, but expecting performance improvement is unlikely to occur.

A change in process is needed. To achieve this, fundamental assumptions need to be challenged. There is, therefore, a need to examine other approaches to identification of the research issue than gap spotting. This aligns with the focus on project management research questions presented by Hällgren (2012) who suggests that *“the dominance of "gap spotting" hampers the development of the project field by producing theories that do not challenge long-held, sometimes possibly false, assumptions”* (Hällgren, 2012, page 804).

Following the methodology discussed in the next chapter, chapter four revisits some of the topics covered in this chapter and applies an alternative approach based on “*probematisation*” (Alvesson and Sandberg, 2011) to examine the development of a research focus based on challenging underlying assumptions.

3 Methodology

This chapter reviews scientific principles as the foundations of the research process to locate project management within the scientific spectrum to provide the basis of developing the research topic and focused research issue.

3.1 Introduction

Methodology is critical; “*The decision to study a topic in a particular way always involves some kind of philosophical choice about what is important*” (Easterby-Smith et al., 2008, page 2). This is clarified from the researchers perspective by Grix (2002, page 179) “*It is of paramount importance that students understand how a particular view of the world affects the whole research process*”. Smith (2009, page 30) positions the need: “*Research philosophy is therefore inherent in the study before the research strategy and design is considered*”. The objective is to align the research to the broader common scientific framework to provide a scientific foundation whilst developing a focus that recognises the need for robust research as “*genuine pieces of investigatory science*” (Tranfield et al., 2003, page 207). These dimensions of the research framework are integrated in figure 4 (Smyth and Morris, 2007, page 424) and are also considered by Grix (2002).

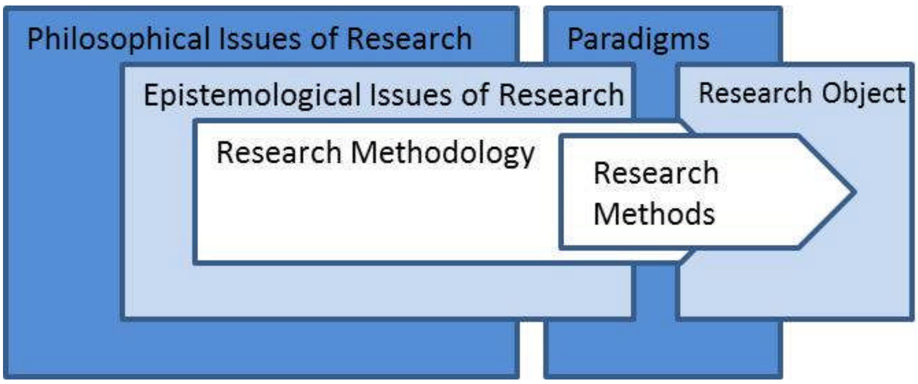


Figure 4: Research foundations

3.1.1 Fieldwork methodology

Overall research methodology was discussed in chapter two. The general research issue of project performance has been discussed and literature review has established that there are multiple issues. Analysis of the issues, with consideration of the industrial context, has allowed a focused research question to be developed. This chapter focuses on the fieldwork methodology appropriate to test the research question. This relates to the stages of the Albores-Barajas, (2006, page 40) model:

- *“Research design”*
- *“Establishment of criteria to evaluate research”*
- *“Development of research tools to build knowledge”*

The development of potential theory is only part of the process. To show its worth it has to be tested. This again opens up a new set of criteria to be considered. To put the dimensions of rigorous scientific investigation into practice it is necessary to design the research process to demonstrate these features.

3.2 Philosophy of science

This section examines the foundation of science and develops a focus on management science and the sub-field of project management (Söderlund 2011). The general position is discussed by Gauch (2003 page 1) who “*explores the general principals of scientific method that pervade all of the sciences*” and references AAAS (1989): “*Scientists share certain basic beliefs and attitudes about what they do and how they work…Fundamentally, the various scientific disciplines are alike in their reliance on evidence, the use of hypothesis and theories, the kinds of logic used, and much more*”.

The scientific method is the most successful process of investigation (e.g.: Gauch, 2003, Börner et al., 2012). ‘Scientific’ investigation must conform to the basic philosophy of a “*systematic process of collecting, analyzing and* *interpreting information (data) in order to increase our understanding of a phenomenon*" (Leedy and Ormrod, 2010, page 2), or as Easterby-Smith et al. suggest:

> *"Hypothesis and deduction: science proceeds through a process of hypothesizing fundamental laws and then deducing what kinds of observations will demonstrate the truth or falsity of these hypotheses."*
>
> Easterby-Smith et al. (2008, Table 4.1 page 58)

This supports the reduction of "*the complexity of the world into experiments, and these may be validated in that they are repeatable*" (Leedy and Ormrod, 2010). This allows "*the intimate connection with empirical reality that permits the development of a testable, relevant, and valid theory*" (Eisenhardt, 1989**,** page 532, citing Glaser and Strauss, 1967) to be achieved.

3.2.1 Philosophical foundations of research

Figure 4 identified the philosophical issues of research as the foundation on which research activities are developed. Building on the basic scientific principles, the purpose of research is to develop theory. The purpose of a theory is threefold, to describe, explain and predict. Figure 5 (Black, 1999 page 3), locates different potential approaches, of which, the empirical systematic and testing hypotheses method on the right hand side is applicable.

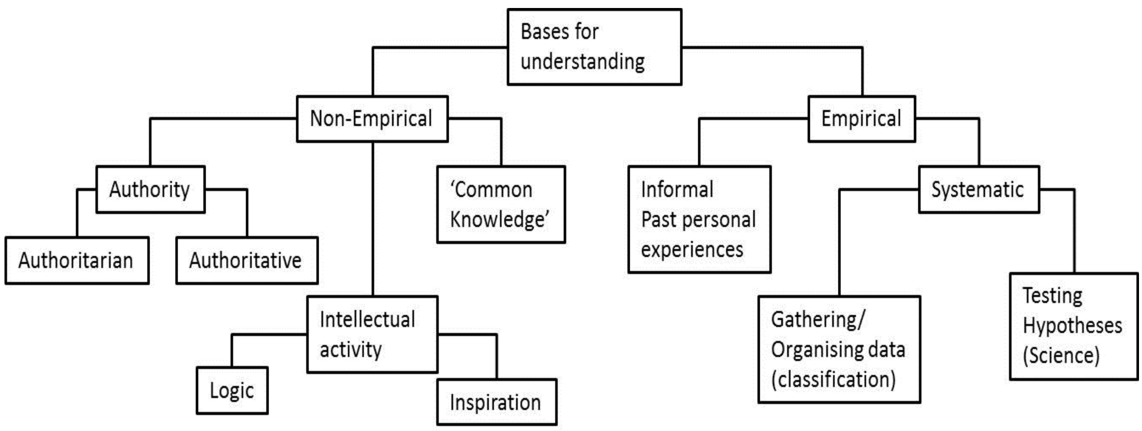


Figure 5: Research forms (Black, 1999, page 3)

Various methods may be employed to test hypotheses:

> *"Experiment is to measure the effects of manipulating one variable on other variables. Survey is to collect information in standardised form from groups of people. [......] Case study is a development of detailed, intensive knowledge about a single 'case', or of a small number of related 'cases'."*
>
> Robinson (1993, page 40)

The specific choice of method (examined in chapter five) is related to the underlying scientific philosophy. Gauch (2003) identifies Kuhn and Popper, amongst others, as the contemporary philosophers of science. Kuhn (1996, (1st edition; 1962)) argues that science only occasionally produces revolutionary ideas. This work identified the paradigm in its contemporary form, the second fundamental topic in figure 4, the function of which is summarised:

> *"These I take to be universally recognized scientific achievements that for a time provide model problems and solutions to a community of practitioners".*
>
> Kuhn (1996, preface, page x)

The principle paradigms are the natural and social sciences; Smith examines Easterby-Smith et al. (1991, page 30) to identify the contrast between them:

> *"Positivism, relativism and social constructionism are points on a spectrum, with positivism and social constructionism taking positions at either end of the scale".*
>
> Smith (2009, page 33, Table 3.2)

Understanding this 'spectrum' and justifying where any particular research should be located requires identification and integration of key characteristics into the broader philosophy of science.

Kuhn (1996, page 43 and 174) extends the paradigm concept to the "*community paradigm*" described as "*a set of recurrent and quasi-standard illustrations of various theories in their conceptual, observational, and* *instrumental applications*" (Kuhn, 1996, page 43). This initial determination might be achieved by examining text books, journal papers, and other relevant materials.

The key characteristic is the mechanism by which the paradigm describes the accepted foundation of the subject and allows anomalies to be identified:

> *"Paradigms provide all phenomena except anomalies with a theory-determined place in the scientist's field of vision".*
>
> Kuhn (1996, page 97)

Kuhn argues that discovering anomalies (by their non-conformance to the paradigm) is a key step in the advancement of science. By identifying the community paradigms of a discipline the basis is established on which anomalies can be determined, research gaps identified and focus developed. Research questions can then be applied, ultimately leading to the introduction of a new paradigm that accounts for the anomalies. Khun argues that it is this iterative process that allows scientific investigation to progress, and is labelled as "*Normal science*" (Kuhn, 1996, Chapters II to IV). This approach is applicable where there is an established community paradigm. As Kuhn argues: "*the paradigms of a mature scientific community can be determined with relative ease*" (Kuhn 1996, page 43). Establishing research issues by identification of anomalies, or the location of 'knowledge gaps', against the background of an established community paradigm is a common approach, typically termed 'gap-spotting'.

However, 'gap-spotting' does not fundamentally challenge the underlying theoretical foundations of the discipline being researched, and consequently may not allow research to be as "*interesting*" (in the context of Davis, 1971) where it challenges the "*assumption-ground*" (Davis 1971, page 311) of the audience, or community. The dominance of gap-spotting is seen as "*surprising given the increased recognition that challenging assumptions is what makes a theory interesting*" (Sandberg and Alvesson, 2011, page 25). The argument is that "*gap-spotting questions are unlikely to lead to significant theories because they do not question the assumptions which underlie existing literature in any* *substantive ways*" (Sandberg and Alvesson, 2011, page 25) and that "*gap-spotting is more likely to reinforce or moderately revise, rather than challenge, already influential theories*" (Sandberg and Alvesson, 2011, page 25). This is given focus in the project management context by Hällgren (2012, page 804) who argues "*that the dominance of "gap-spotting" hampers the development of the project field by producing theories that do not challenge long-held, sometimes possibly false, assumptions".* Hällgren (2012, page 804) suggests: "*Researchers are therefore urged to become bolder in their claims*".

Locke and Golden-Biddle (1997, page 1055) identify two processes for contribution: '*Structuring intertextual coherence*' and "*problematizing the situation*". Another approach is promoted by Carlile and Christensen (2005) who describe research as "*anomaly seeking"*; that anomalies to the existing paradigm / theory form the basis of investigation, which, when formalised, support the advancement of knowledge. Sandberg and Alvesson (2011) and Alvesson and Sandberg (2011) recognise 'gap-spotting' as the dominant mode of identifying research questions, but suggest "*probelmatization*" might be a more interesting alternative approach. Sandberg and Alvesson, (2011, page 32) promote problematization "*as a means to identify and challenge assumptions underlying existing theory and, based on that, being able to formulate more informed and novel research questions",* from which focused research can be conducted resulting in generation of new knowledge.

Fundamentally, gap spotting makes the assumption that the research field is theoretically sound. If a first principles review shows the underlying theory and the topics between which the gap is located require further development, then gap spotting may be inappropriate. An analogy is building a bridge; it is necessary to have firm ground on both sides. In these cases, alternative approaches are needed. This position can be tested by identifying the community paradigm, and assessing its ability to provide the "*theory determined place*" described by Kuhn (1996, page 97). However, for subjects without an established community paradigm, it will be challenging, if not impossible, to define "*key research questions*" Kuhn (1996, page 15) explains: "*In the absence* *of a paradigm or some candidate for paradigm, all of the facts that could possibly pertain to the development of a given science are likely to seem equally relevant*".

The need to develop the theoretical foundations to identify an accepted community paradigm is recognised:

> *"If the actors in the preparadigm community eventually gravitate to one of these conceptual frameworks……then the phase of "normal science" begins."*
>
> Bredillet (2010c, page 6)

There is historic example of the process of "*gravitating to one of these conceptual frameworks*"; in describing the development of physical optics prior to publication of "*Opticks*" (Newton, 1704), Kuhn identifies the pre-paradigmatic state; "*No period between remote antiquity and the end of the seventeenth century exhibited a single generally accepted view about the nature of light"* (Kuhn, 1996, page 12). Newton's publication provided the community paradigm.

3.2.2 Criteria for rigorous scientific research

Having examined the underlying philosophy of science and the role of the community paradigm, structuring research is the next step. It is appropriate to consider the practicalities of generating knowledge and the criteria required to ensure scientific rigour.

3.2.2.1 Knowledge and contribution

The definition of knowledge is considered by Morris (2000), which may be summarised as being the interpretation of information in order to contribute to the development of theory. It is necessary to consider how research is structured to obtain knowledge and applied to develop theory. Subsequently, there is a need to conduct testing to support validation.

Whetten (1989, page 492) identifies several criteria that constitute 'contribution'; of these *"what"* and *"how"* questions could be relevant, but typically unlikely to contribute to development. Additionally, "*who*", "*when*" and "*where*" questions are generally "*insufficient to point out limitations in current conceptions of a theory's range of application*". This leaves "*why*" questions which are "*probably the most fruitful, but also the most difficult avenue of theory development*".

Whetten (1989) indicates an alignment with the concept of the paradigm (*"Theories often are challenged because their assumptions have been proven unrealistic*" Whetten, 1989, page 493), and its development in recognising an existing knowledge base applicable to a discipline, but also suggests challenging underlying rationales and assumptions is a significant element of developing new paradigms.

3.2.2.2 Scientific rigour

It is also necessary to examine the conduct of research and the need for rigour. Denzin and Lincoln (2003) identify the concepts the paradigm encompasses: *"ethics (axiology), epistemology, ontology, and methodology"* Denzin and Lincoln (2003, page 245).

Ethics asks: "*How will I be as a moral person in the world?"* It is fundamental to ensure that research is ethically sound.

"*Ontology logically precedes epistemology which logically precedes methodology*" Grix (2002, page 178), so although the third concept identified by Denzin and Lincoln (2003), ontology is reviewed first. Gauthier and Ika (2012, page 6) describe ontology as: "*the image of social reality upon which a theory is based*" and suggest "*there should be a set of ontological commitments or presuppositions, which Lakatos (1970) coined as the hard core for any science*".

The second concept identified (Schwandt, Chapter 7, pages 189 to 214, in Denzin and Lincoln, 2003) is epistemology. Grix (2002) describes Epistemology as focusing "*on the knowledge-gathering process and is concerned with developing new models or theories that are better than competing models and theories*" (Grix, 2002, page 177), and quotes Blaikie (2000) to define it as: "*the possible ways of gaining knowledge of social reality, whatever it is understood* *to be. In short, claims about how what is assumed to exist can be known"* (Blaikie, 2000, page 8).

3.2.3 Philosophy of management science

Building on the overview of scientific investigation, this section develops the focus onto the management sciences to identify the key characteristics that locate them on the research spectrum and establish their differences from other disciplines.

To consider the foundation for research in management science, the underlying philosophy needs to be addressed to establish its location on the research spectrum such that an appropriate paradigm can be identified to allow research methodology to be considered. Different perspectives can be taken, for example, Hatchuel (2009). The argument presented is that the key characteristic differentiating management sciences is 'design', meaning that the objectives and their management processes are pre-defined: they are controlled and can be modified. This differs from both the natural and social sciences paradigms.

Focusing on management science, in a special issue of Academy of Management Review, Van Maanen et al. identify the challenges that "*explore how theory and method inevitably interact in particular organization and management studies*" (Van Maanen et al., 2007, page 1145). They suggest "*that respecting both the primacy of theory and the primacy of evidence is no easy task but a necessary balancing practice that characterizes high-quality research*" (Van Maanen et al., 2007, page 1145). Hameri et al. (2002) identify the overall objective:

> *"The objective is to study the organizational behaviour and to translate the results into a language explaining the phenomena from managerial point of view"*
>
> Hameri et al. (2002, page 610)

The definition of Management sciences is discussed by Easterby-Smith et al. (2008), and Bryman and Bell (2007). The questions are: What is the ontological and epistemological position of the management sciences? Do they locate at either end of the scientific spectrum? The common view is that they are typically viewed to be positivist, and attempting to apply a natural science approach, although this might be challenged.

Hatchuel (2005, page 37) proposes '*collective action'* as an epistemological position for management sciences, supporting the argument that management science is a basic discipline aligned with neither end of the spectrum. Management processes differ from the natural sciences focus of testing hypotheses by observation of phenomena whose behaviour is "*independent of the observer*" where the positivist paradigm *"Concrete and conformable to law from structure independent of the observer*" (Arbnor and Bjerke, 1997, page 25) is present. Management processes are carried out by people who work them, who will influence their behaviour. But neither are they pure social processes where the observation and analysis of behaviours approach is taken and the social constructivist paradigm that reality is a "*manifestation of human intentionality"* (Arbnor and Bjerke, 1997, page 35) is applicable because there is an expectation of repeatable and predictable process performance.

The need for a diversity of approaches to research and where management research was located is argued by Whitley (1984a, 1984b), who reinforces the above discussion and supports the view of a spectrum of research activity on which the management sciences are located.

Whilst the approach to examining the underlying research philosophy was intentionally generic to consider the broadest application, it is necessary to recognise the nature of research into organisational and management sciences. This provides the foundation for focused research and will allow the process of generating knowledge to be examined within the sub-field of project management research (Söderlund, 2011).

3.2.3.1 Applied example: project management

The initial discussion in this chapter has intentionally been independent of application so that the location of project management can clearly be developed and its theoretical foundations discussed and grounded in rigorous science. This section develops the focus of the link between scientific structure and project management's theoretical foundation as the basis for investigating the emergence of tools and techniques and their influence on project performance. In the context of project management, the philosophy of science is discussed by Jugdev (2008). Morris (2013b, page 8) clarifies the situation: *"After all, project management is a social construct; projects are 'invented not found'"*. An initial consideration is the underlying philosophy:

> *"Certainly, there should be doubts about the wisdom of applying a positivist paradigm, based on rules and certainty, to a project-based scenario involving unique actions undertaken in an uncertain and turbulent environment".*
>
> Leybourne (2007, page 62)

Consequently an underlying philosophy that recognises the nature of the variable is required. The difference between the natural sciences and project management is the potential to control the key characteristics of the project objectives. Design Science is examined as a candidate; Winter et al. (2006) identify the difference that prompts the investigation:

> *"This suggests there is a need to reconsider how the theoretical foundations and subject paradigm might be developed. (This is where a focus on the purpose of PM might be relevant – and that the objectives can be defined, so considering the requirements for a definition of a subject paradigm are easier, because the end game is known – thus there is a difference in management science to the philosophy that is drawn from the natural sciences)."*
>
> Winter et al. (2006)

3.2.3.2 Management, project management and design science

The discussion of the location of management science and project management has highlighted some significant issues. The suggestion by Winter et al. (2006) that "*the end game is known*" and that "*there is a difference in management science to the philosophy that is drawn from the natural sciences*" needs to be explored further. Management science does not readily locate in either the natural or social sciences on the scientific spectrum. Tranfield (2002a) argues the relevance of both scientific discipline and advancement of practice, and cites:

> "*The key defining characteristic of management research is its applied nature"*
>
> *"And its central concerns should be: "the general (engineering problem) of design*"
>
> Tranfield and Starkey, (1998, page 341)

'Design' is considered to be where the organised application of tools, techniques, processes and behaviours are expected to achieve pre-defined objectives. As expected performance is controlled, failure investigation focuses on required change to deliver the expected result, although there is the option to change the overall objective. It is this pre-defined nature of the objectives, and the opportunity to re-define them, that challenges the basis of scientific investigation, and the appropriateness of a particular philosophy for research. This is fundamentally different from both the natural sciences positivist paradigm and the social sciences where the social constructivist paradigm is prevalent. A management sciences paradigm needs to be considered.

The contemporary concept of 'design' as a scientific phenomenon is attributed to Simon (1996), who describes the "*science of the artificial*". Barnes (2000) suggests that Aristotle originally described the concept as the '*science of production'*. Simon suggests:

> *"Everyone designs who devises courses of action aimed at changing existing situations into preferred ones".*
>
> Simon (1996, p111)

This could be used to describe the purpose of a project, and suggests that projects, and their management, are aligned with the design science philosophy.

Simon's concept was developed by Kroes (2002) and van Aken (2004, 2005). Others (van Aken and Romme, 2009; Denyer et al., 2008), build the argument for design science. Tranfield (2002b) builds on the work of van Aken to offer "*a vision of management research as a design science, serving academic need for rigour and research quality and practitioner requirements for relevance and applicability of findings*" (Tranfield, 2002b, page 409). Tranfield concludes *"Challenging management research to become a design science is in contrast to the conception of management research as an explanatory science which seeks to identify and formulate 'the natural laws of management and organisation'"* (Tranfield, 2002b, page 412).

The need for both scientific objectives and research orientated partnerships is recognised by Hatchuel (2001) who discusses the philosophical foundations of management science and recognises the design aspect and includes design science with theory development. Niehaves (2007, page 100) acknowledges Iivari (2007) and concludes "*A comprehensive integrated discussion of epistemology in information systems design science is not yet to be found*", indicating that more work is required.

Hatchuel (2001), Hodgkinson and Rousseau (2009) and Pandza and Thorpe (2010) examine the position of management sciences within the design sciences. The relation to critical realism has also been debated (Hodkinson and Starkey, 2011, Willmot, 2012, Hodgkinson and Starkey 2012). Farrell and Hooker (2012) argue against the concept by suggesting that natural science and design do not produce distinct types of things. Farrell and Hooker (2012) is not accepted as it is argued that the relationship to the unit of analysis is the difference, particularly the potential for the observer to influence the behavior of the unit of analysis, so there is a case. Galle and Kroes (2014) develop this argument. Tranfield (2002b, page 412) sets the challenge: *“management researchers might begin to build a rigorously developed and exciting field in which both academics could thrive and managers have confidence”.*

Kuhn (1996) and Simon (1996) could provide the combination of the paradigm model and the artificial science nature of project management as a philosophical basis for the subject. Cioffi (2006) and Ahlemann et al. (2013) consider project management in a design science context. An initial view would be that project management generally meets the criteria of design science.

3.3 Research classification and framework

The discussion above considers the fundamental structure of scientific analysis and discusses how specific research areas and topics are located in relation to the broad philosophy of science. This is developed to consider the location of the natural and social sciences and identifies ‘design science’ as the location for the production of artefacts which encompasses the management sciences and project management. This section integrates these different aspects to consider how they show an overall picture.

A framework can be drawn to illustrate the relationship of pure scientific research to that of the social sciences. Figure 6 (page 80) shows these differences and the range of views between them and integrates various aspects of the scientific structure discussed previously and utilises material from various literature references. This range includes the paradigm descriptions (Arbnor and Bjerke 1997, Table 2.1, page 27 and figure 2.2, page 46) and design science (Simon 1996), in which the management sciences and the example of project management can be located and from which the development of the various research methods might be considered and how they relate to quantitative and qualitative approaches. This basic structure can then be related to the range of paradigms and approaches to research. This allows the subject area and research focus to be located on the research spectrum, from which it is possible to consider the location of specific research activity.

3.4 Research methodology

The purpose of the previous section was to examine the overall structure of scientific research and to consider it in the context of the management sciences. This section examines developing and applying an overall methodology to practical investigations. Recognising the difference between methodology and methods is discussed by Grix (2002). Methods are discussed in chapter six.

Developing the need to have a sound foundation for research, this section identifies the various aspects that constitute a research framework, and how they integrate to support the research activity. Given the initial discussion around the philosophy of science, and the need for ontology and epistemology, and the discussion that management sciences need to be considered in a different context to the natural sciences, the next question is: What framework is available to conduct useful (effective for theory and practice) research into the management sciences?

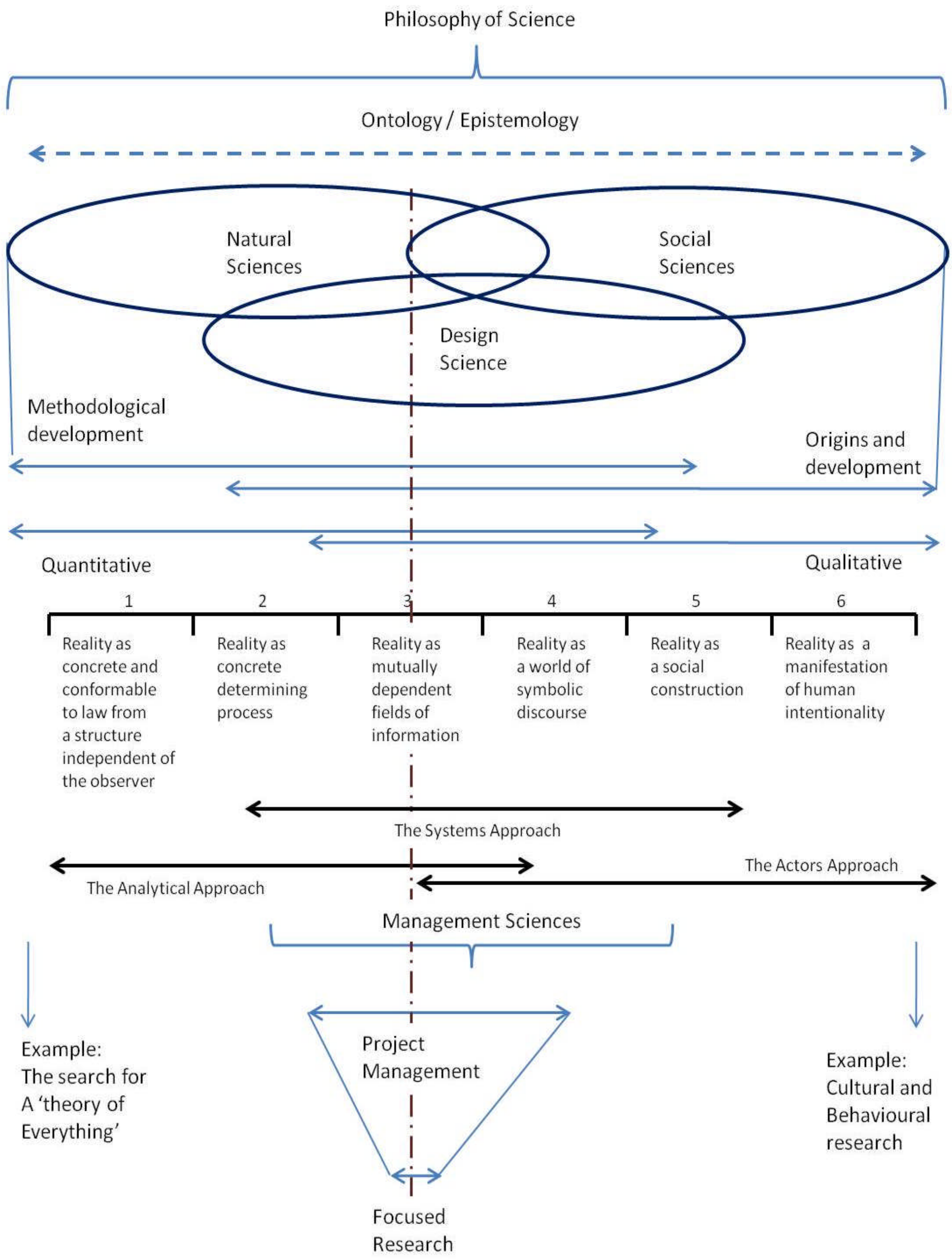


Figure 6: Relationship between philosophies of science, paradigm, management science and project management research.

(Note: figure six is an illustrative integration of the various topics discussed and relevant references mentioned above to show the relationship between the general philosophy and the focused research topic)

3.4.1 Methodological models

Having established the spectrum of paradigms, and their underlying philosophical elements, the linkage to the overall research methodology can be developed. Arbnor and Bjerke (1997 page 26) provides a discussion considering the relationship between paradigms and methodological approaches. Numerous models have been proposed to represent the structure of a research framework (Several are summarised by Smith (2009)). Easterby-Smith at al. (2008) and Bryman and Bell (2007) also discuss methodological models. Review concluded that the model by Meredith (1993) was appropriate and relevant, as developed (Albores-Barajas, 2006, page 40), figure 7.

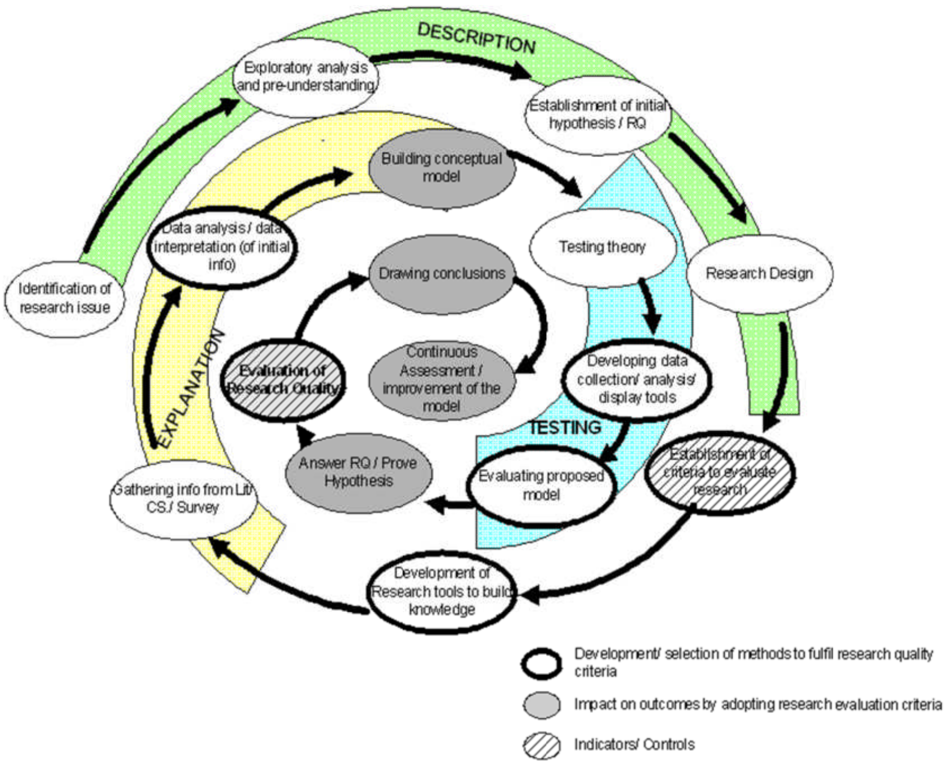


Figure 7: Research Cycle (Albores-Barajas, 2006, page 40)

Development of the Meredith model to show clear focus of the research would be advantageous, as would feedback and closing the loop back to the original research question, as part of the overall cyclic nature of the research process.

These issues might be approached by first considering the model introduced by Rook (1986, figure 3, page 11) for the control of software projects (figure 8). Rook's model identifies the basic concept of decomposition on the left hand side to a focused work activity at the base and integration towards the final product. The model is generically known as the ‘V’ model or ‘V’ diagram. One of the additional advantages is that it allows for feedback and testing that each level of integration (on the right hand side) relates to the initial decomposition (on the left hand side).

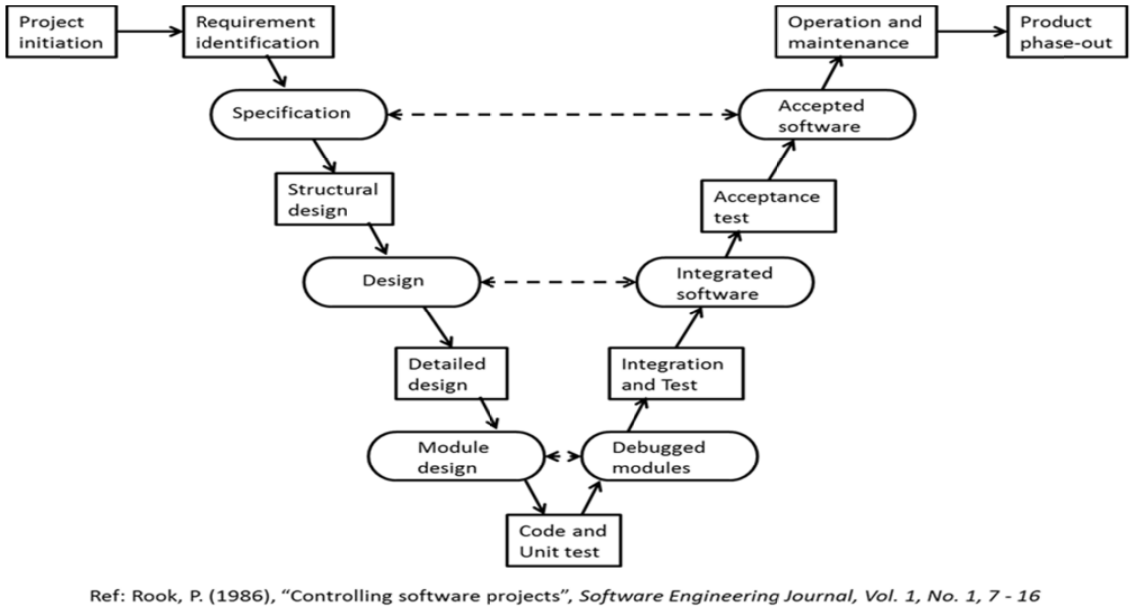


Figure 8: ‘V’ diagram (Rook 1986 page 11)

The main strength of the V model is its graphical representation of the focused activity that the decomposition on the left is working towards and the subsequent integration towards the overall objective on the right. This provides a useful model for research activity as the single diagram embodies many of the features fundamental to the structure of research activity.

The V model, figure 8, (Rook 1986, page 11) can be developed to represent the research process by mapping the development of the Meredith model by Albores-Barajas (2006, page 40) (figure 7), as shown in figure 9. It visualises the decomposition of the initial problem towards the focused research activity, which could be considered as the deductive aspects of research, and the integration of the solution towards theory, which could be considered to be the inductive aspects of the research process. Additionally, feedback and closure of the research loop is easily incorporated.

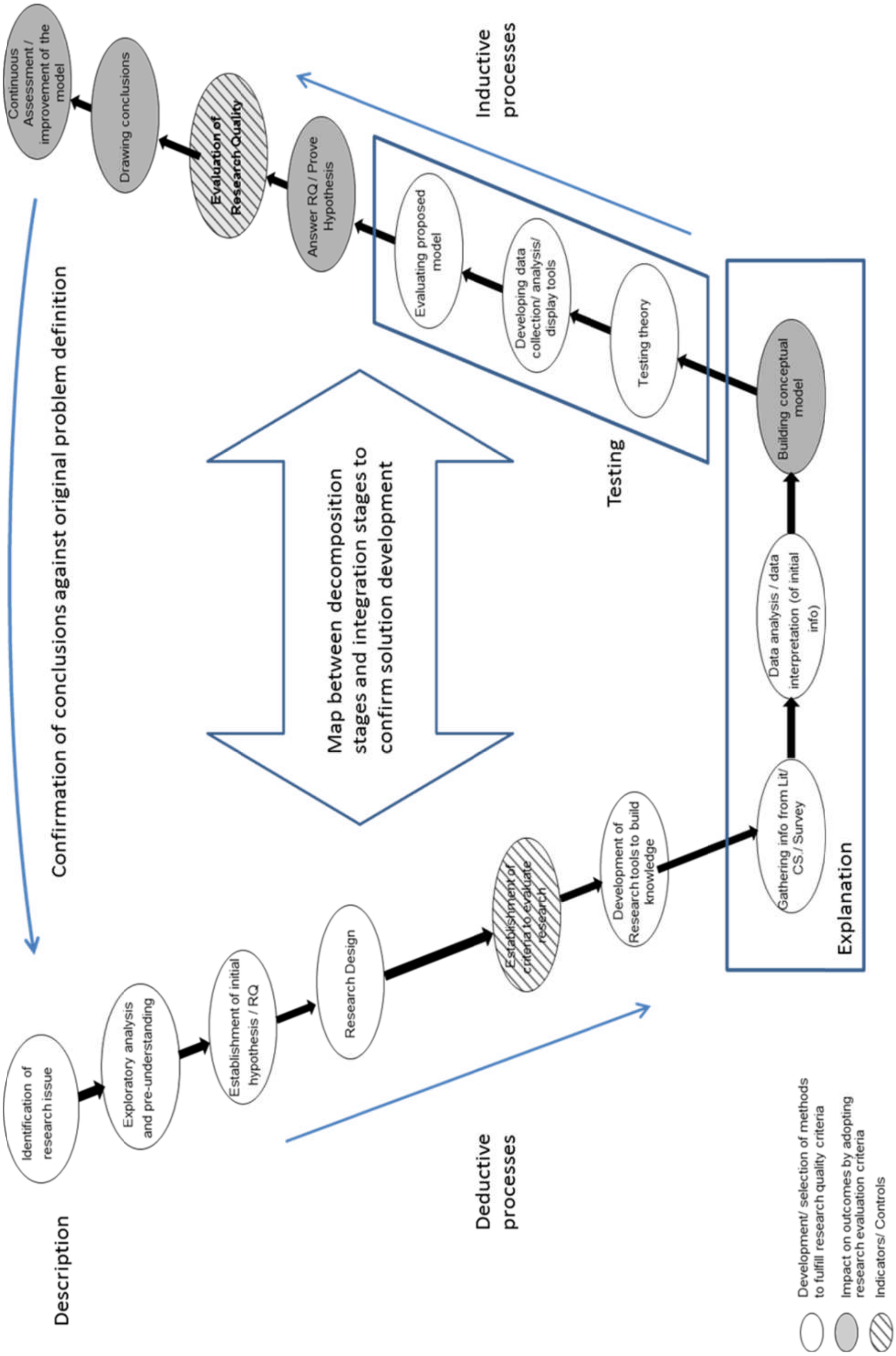


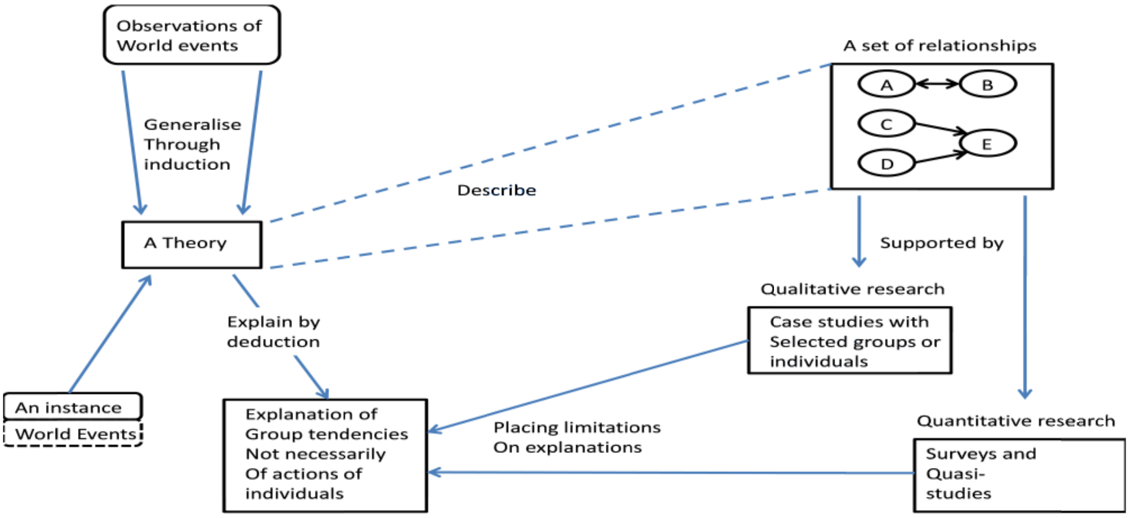
Figure 9: Integrated research process model

3.5 Theory building

The objective of scientific investigation is to improve theory. This section develops the previous discussion to examine theory building. The challenge that this presents is made clear by Eisenhardt (1989, page 532), when discussing the *“intimate connection”* between theory and nature. *“In general, a theory states causality between isolated dependent and independent variables”* (Voordijk, 2011, page 336).

The challenge of achieving theory development may vary between the natural and social sciences. The complexity of achieving this generally, or in the context of management research, attracts specific contemporary attention, for example, Adner et al. (2009 page 201) who argue the case for formal theory and present *“an overview of these methods and their advantages as tools for theory building”.*

The discussion so far has considered the philosophical foundations and methodology of research. This provides a framework to support the development of theory in order to gain, and make sense of, knowledge. This focuses on developing theory as a description of a phenomenon to understand and predict behaviour. Understanding what is meant by theory is critical to understanding how specific research needs to be designed to be relevant. Wacker (2008) and Van de Ven (1989) both discuss theory development. This is necessary to *“build knowledge through refutation of our theories”* (Morris, 2002, page 87), i.e. to examine a topic in a manner that can test the validity of the theory. This can be summarised in the overview of the theory building process in figure 10 (Black 1999 page 9). The general approach is to identify a research and community paradigm and define anomalies or seek gaps in the knowledge, alternatively, to identify underlying assumptions that should be challenged (Alvesson and Sandberg 2011) in which to locate focused research. This allows research questions to be defined, the investigation of which generates knowledge that can be analysed to build theory. Carlile and Christensen (2005) develop the discussion to consider the theory building process and its transition from descriptive to normative. They discuss the role of discovering anomalies in building better theory and consider the process of building theory whose validity can be verified.



Theory building through induction, confirmed by research, and used by deduction to try to explain instances,
But limited by the nature of the research support for the theory (developed from an idea presented in figures
From Gilbert, 1993)
(Ref: Black, Doing Quantitative Research in the Social Sciences – Figure 1.2 pg 9)

Figure 10: Theory building (Black 1999, page 9)

As discussed by Smith (2009), Carlile and Christensen (2005, page 1) examine "*data, methods and theory*" to provide an overview of the problem, focused on management sciences, they describes the transition from descriptive theory to normative theory. Carlile and Christensen (2005, page 1) "*synthesizes the work of others who have studied how communities of scholars* [4] *cumulatively build*

---

[4] *"This model was developed first by synthesizing models of theory building that have been developed by scholars of this process in a range of fields. These include Kuhn (1962) and Popper (1959) in the natural sciences; and Campbell & Stanley (1963), A. Kaplan (1964), Glaser & Strauss (1967) Stinchcombe (1968), Roethlisberger (1977) Simon (1976), Yin (1984), R. Kaplan (1986), Weick (1989),Eisenhardt (1989) and Van de Ven (2000) in the study of management and social science. To this synthesis we have added our own observations, derived from studying various doctoral students' research efforts at Harvard, MIT, Stanford and the University of Michigan".*

valid and reliable theory". This is further developed in chapter nine to examine the integration of the research to general theory.

It is also important to consider if research is 'descriptive' or 'prescriptive':

> *"Descriptive research is a knowledge-producing activity mainly associated with the explanatory sciences, such as natural science but also social science (Voordijk, 2009). Prescriptive research is a knowledge-using activity corresponding to design science, the science that develops knowledge that professionals can use to design solutions for their field problems (Van Aken, 2005)".*
>
> Voordijk, (2011, page 334)

Prescriptive theory is the 'in case of x do y' approach. When extended to the general application in the subject area, a particular tool or technique provides a mechanism that supports performance improvement. This research intends to be descriptive, although the research focus is likely to be prescriptive.

3.5.1 Theory building in the management sciences

Developing a focus on management sciences, the objective is to locate the general research area within the overall scientific framework and the research spectrum in figure 6. If management science is located between the natural and social sciences, and should be considered as a design science as discussed in section 2.2.3.2, then theory building will draw on both natural and social science approaches.

3.5.2 Theory building in project management research

This section develops the research focus on to project management in the context of overall research structure (figure 6).

The purpose of project management research is given by Anagnostopoulos (2004, page 257): "*Project Management needs descriptive theories from which heuristics can derive, which will enrich the cognitive apparatus of project managers for confrontation with special situations*".

Building on the discussion in section 2.2, establishing the community paradigm will allow anomalies to be identified in order to define the point of departure for research. Theory building is examined: Jugdev (2004) discusses several dimensions of theory building in a project management context and from the resource perspective. Jugdev (2008) identifies other authors e.g. Jacobsson and Söderholm (2011), who consider the problem of project management theory, and offer a point of departure for discussion on project management theory development.

Project management is a sub-field of management science (Söderlund, 2011) and can be considered to be an application of design science (Cioffi, 2006), (Ahlemann et al., 2013). Whilst Cioffi (2006) focuses on EVM, the underlying argument of the need for a community paradigm and that project management is located in the artificial sciences due to the designed nature of the process, has application to a broader set of tools and techniques than just Earned Value Management.

Hanisch and Wald (2011) and Ahlemann et al. (2013) tackle the problem of project management research and developed research frameworks. To develop a suitable research focus, it is necessary to examine the key issues of project performance. Extending the frameworks of Hanisch and Wald (2011) and Ahlemann et al. (2013), if projects could be kept on track, their performance would be acceptable. Project failure is a consequence of deviation from plan. However, as projects are complex activities across networks of tasks, a simplification would be to examine task performance.

The initial concern around developing a research question is the quantity of literature available, in terms of ensuring that the question is relevant to the broad picture of project management. This section examines the process of developing research questions, with a focus on research questions in project management.

Any research requires an understanding of the philosophical position. Therefore: how does the philosophical positioning influence the development of the research question? The discussion given in this section considers the underlying philosophy and methodology of research. It is necessary to consider this in the context of the development of project management research questions.

The lack of coherence and evidence of a structured theoretical foundation suggests that ‘gap filling’ would be an inappropriate approach due to the lack of existing paradigm. Therefore the adoption of the problematization approach of Alvesson and Sandberg (2011) offers an approach that supports the development of questions that challenge the underlying basis by challenging underlying assumptions of the subject rather than filling gaps and is more appropriate to guide the development of the research question.

3.5.2.1 Research questions

The cornerstone of research is the research question. The initial research investigation develops the research question, based on application of basic philosophy and decomposition of the subject area. The subsequent activity investigates the question and integrates the results towards the general theoretical body of knowledge for the subject.

Examining “why” questions, Whetten (1989, page 493) suggests: “*It commonly involves borrowing a perspective from other fields, which encourages altering our metaphors and gestalts in ways that challenge the underlying rationales supporting accepted theories. This profound challenge to our views of human nature, group development, organisational transactions, and so forth, generally precipitates a broad reconceptualization of affected theories*”. Although the discussion by Whetten (1989) suggests ‘how’ questions are not as relevant or challenging as ‘why’ questions, the focus on a ‘how’ question here is an element of the broader ‘why’ question. The expectation is that the research focus will identify further work that will progress the resolution of the broader, and more interesting ‘why’ question.

3.6 Research design and fieldwork methodology

This section investigates field work methodology and research design.

3.6.1 Qualitative and Quantitative Research methods

Shar and Corley (2006) discuss Qualitative and Quantitative research methods. This provides an outline to explore applicability to focused research and building theory. Qualitative methods are presented in Symon and Cassell (2012) and quantitative Methods in Black (1999), summarised in table 4.

Quantitative methods would be preferred due to their use of metrics, however, because of the multiple dimensions and open systems nature of project management, qualitative methods will be adopted.

Table 4: Differences between Qualitative and Quantitative Method.

Method	**Qualitative**	**Quantitative**
Purpose of inquiry	Understanding the interrelationships of different variables	Explanation and control
Research approach	The researcher is really part of the process being researched (subjective)	Objective
Data	Mainly non-numerical data.	Mainly numerical data
Number of Variables	Look for more variables to enrich the research.	Look to minimise the number of variables from the beginning of the research
Analysis	Descriptive analysis by interpretation of data	Deductive analysis by using statistical techniques
Output	Knowledge constructed	Knowledge discovered
Generalisations	Analytical generalisations	Statistical generalisation
Research questions seeks	Patterns of unanticipated as well as expected relationship.	A relationship between a small number of variables
Approach to Uniqueness	It is treated as an important understanding	It is treated as an error

(Adopted and modified from Stake, 1995:37,40; Yin, 1994:30; White, 2000:28,29,26,4 7)
Martinez-Hernandez (2003, Table 4.3, page 64)

3.7 Data collection Techniques

Numerous data collections techniques are discussed in literature. Examples are: Bryman and Bell (2007), Easterby-Smith (2008), also Martinez-Hernandez

(2003, table 4.4, page 70) Partington (1997 page 68 to 70). Summarised in table 5.

Liu et al. (2010) identified the relationship between task performance and overall project performance, but recognised the survey approach was not ideal. This suggests a different approach to work in this area would be appropriate. Further, Liu et al. (2010) work was based in the IT/IS industry; this research examines the issues raised by Liu et al. (2010) on a broader basis, considering project management as an independent discipline.

Lee (2007, chapter 3) discusses methods. These methods can be referenced back to ‘standards’.

One of the concerns is to ensure that the research paradigm aligns with the research method to be employed and to ensure that they are compatible, and appropriate for the work being carried out, as discussed by Smith (2009).

Table 5: Strengths and weaknesses of the data collection techniques

Source of Evidence	Strengths	Weaknesses
Action Research	• it positions in the understanding and logic • it can help to facilitate an improvement or wider improvements.	• it is not appropriate to make generalisations for a population as a whole. • There is a danger that the researcher becomes too involved in the whole process. • it is very time consuming.
Case Study	• Provide rich quantity of unpublished data • It gives a work reality, which is often absent from surveys. • It is cheap; even one researcher can conduct it. • Does not compromise the objectives and time of the organisation under research.	• It is time consuming but not as much as action research. • The whole issue of generalisation should be handled with caution • Since the case study provides rich information, this has to be handled logically and systematically
Survey	• data gathering is less time consuming • easy data gathering	• lack of control over who answers the questionnaire • possible ambiguity of the questions • potential low response
Interviews	• targeted- focuses directly on the topic • insightful-provide perceived causal inferences • when it is face-to-face the interviewer can clarify misunderstandings. • Effective for collecting large quantities of in-depth data. • Researcher is not required to spend long periods of time on site.	• Bias due to poorly constructed questions • Response bias • Reflexivity- the interviewee give what the interviewer wants to hear • One interview equal to one example of the whole population • Interviewing is time consuming • Data analysis is time consuming • Requires the researcher to gain access to the knowledge and meaning of informants.
Questionnaire	Very time efficient for researcher and respondents • Respondents can be quantified for ease of analysis	• Data collection depends on respondents goodwill • Quantity of data collected is limited • No opportunity for clarifications and deeper questions
Documentation	• Stable- these can be reviewed repeatedly • Data can be traced back over time • Multiple source can facilitate data triangulation	• Documents may be limited and unavailable • Bias selectivity
Direct Observation	• Reality- covers events in real time • The researcher obtains the information from first hand so he/she can give a better interpretation of the phenomena	• Time consuming • The event may proceed differently because it has been observed.
Diary Records	• Get information from the perspective of the employee. • Very appropriate during data analysis and writing up stage	• Difficulty to analyse the data
Archival Records	• Precise and quantitative	• Accessibility due to privacy reasons

(Adopted and Modified from: Barnes 2001; Moser and Kaltan, 1971;
White 2000:29,42,43;Yin 1994:80).
Martinez-Hernandez (2003) – Table 4.4 page 70

3.8 Develop the focused fieldwork methodology

The selection of specific methodology has to meet several criteria in relation to theory building and testing. This section considers how specific research methods are applicable to the proposed research methodology and philosophical framework.

At this stage, the initial identification of the research area needs to be aligned with the underlying philosophical framework to allow the proposed research activity to be structured.

Following consideration of the various techniques, case study appeared most relevant.

> *"Case studies often focus on the relationships and processes of a phenomenon, which tend to be interconnected and interrelated, and to understand one thing it is often necessary to understand the linkages between all the factors (Denscombe, 2002)."*
>
> (Smith 2009, page 41)

The case study approach may not be considered to focus on sufficient detail to support the positivist reductionist approach.

It was decided that 'Critical Incident Technique' (CIT) (Flanangan 1954) would be relevant to investigate the detail of tasks and incidents of deviation. The combination of Case Studies and CIT is such that CIT provides the focus within the case study to meet the requirements of positivism.

3.8.1 Case Studies

Having selected the case study as the primary approach to the fieldwork, the next stage is to consider the design required to achieve a rigorous and methodologically sound investigation.

This section examines the case study methodology (Yin, 2009). It is necessary to consider the requirements of using a case study approach and ensure that they align with the philosophical criteria.

Eisenhardt (1989) considers the theory building aspects of the case study results. The 'road map' presented by Eisenhardt (1989) can be considered in conjunction with Yin (2009). Case studies are most appropriate for "how" and "why" questions. The research question, derived in chapter four, is a 'how' question. Partington (1997, page 63) discusses Yin and the five components of case study research design:

- **A study's questions,**
  From the initial research questions (developed in chapter 5), develop the specific research questions.

- **Its propositions, if any,**

  > *"each proposition directs attention to something that should be examined within the scope of the study."*
  >
  > (Yin, 2009, page 28)

  Develop the 'propositions', (Yin, 2009, page 28) including the deviation lifecycle model – that can then be tested.

  - If the basic problem is project performance, then propositions need to focus on gathering data on aspects that enhance or inhibit performance.
  - Analysis needs to test whether these aspects can be identified before the event.
  - Can action be defined and applied to minimise adverse impact?
  - Does the analysis provide an opportunity for the project manager to implement action prior to a project deviation emerging?

- **Units of analysis**

  Define the unit of analysis for the investigation being carried out.

The unit of analysis is “deviation”, the difference between the planned and actual delivery of the project. This is required to quantify the potential impact the failure of task delivery will have on overall project delivery performance.

If the research is successful, it will be possible to reduce the level of ‘deviation’ occurring in a project task.

- Can deviation be measured at the task level?
- How can it be corrected?
- Are the project performance criteria of Budget, Schedule and Specification applicable to the task?
- Can task deviation be measured using these criteria?

If ‘deviation’ can be measured, then it must relate to a source at an earlier stage of the task lifecycle. What is the ‘maturity’ process, and can the source be traced?

- **The logic linking the data to the propositions,**

Analytic techniques are discussed by Yin (2009, Chapter 5): *“Four General Strategies: Relying on theoretical propositions*, *Developing a case description*, *Using both qualitative and quantitative data*, *Examining rival explanations”* (Yin, 2009, Pages 130 - 136).

Examine these options – consider the appropriate analysis route

- **The criteria for interpreting the findings**

Yin (2009, Chapter 5) discusses ways of linking data to propositions: *“Pattern matching*, *Explanation building*, *Time series analysis*, *Logic models*, *Cross-case synthesis”* (Yin, 2009, Pages 136 - 160).

Criteria for interpreting a study’s findings:

Identify and address rival explanations (include this as part of data collection / discussion).

3.8.2 Critical Incident Technique

This section develops the application of Critical Incident Technique (CIT) to this research, and uses Flanagan (1954) and Butterfield et al. (2005) as guidance throughout.

Originating in Psychology and the social sciences, CIT's application has been extended and includes limited application to project management (13 of more than 1200 studies identified that utilising CIT has been associated with Project Management).

Research into projects, and particularly analysis of deviation, may be regarded as a critical incident – the future progress of the project is at stake. CIT – could actually be seen as a strength for project management research – bringing a new technique to the field (research if anybody has done any project management research using CIT and specifically, researching the task level performance) – CIT can bring a new perspective, and therefore new knowledge. – Then review – the logic for using CIT etc.

> *"Measures of typical performance (criteria). The simplest and most natural application of a systematically collected set of critical incidents is in terms of the preparation of a statement of critical requirements and a check list or some similar type of procedure for evaluating the typical performance of persons engaged in this activity".*
>
> Flanagan (1954, page 21)

None of the studies use CIT to focus on the level of detail being investigated in this research. Therefore, this research extends the application of CIT. This extension of the application of CIT needs to be tested to examine if it is a valid application.

Use of CIT to focus on the detail – part of research design. CIT being used to investigate the detail of tasks and incidents of deviation.

Elements of the CIT process

What is the CIT process? And, how can it be applied to this investigation? – Define the data collection process and the relationship to the research objectives (as defined in chapter 5).

There are 5 aspects of the CIT process from Flanagan (1954, pages 9 - 21):

- ***"General Aims***
  A basic condition necessary for any work on the formulation of a functional description of an activity is a fundamental orientation in terms of the general aims of the activity.

  > *"These requirements include those which have been demonstrated to have made the difference between success and failure in carrying out an important part of the job assigned in a significant number of instances".*
  >
  > Flanagan (1954, page 3)

- ***Plans and Specifications***
  To focus attention on those aspects of behavior which are believed to be crucial in formulating a functional description of the activity, precise instructions must be given to the observers.

- ***Collecting the data***
  If proper plans and specifications are developed, the data collection phase is greatly simplified.

- ***Analysing the data***
  The purpose of the data analysis stage is to summarize and describe the data in an efficient manner so that it can be effectively used for many practical purposes.

- ***Interpreting and reporting"***

  It is never possible in practice to obtain an ideal solution for each of the practical problems involved in obtaining a functional description of an activity. Therefore, the statement of requirements as obtained needs interpretation if it is to be used properly".

Compiled from: Flanagan (1954, page 20)

The general aim of the research has been established, as well as the research question.

> *In summary, the critical incident technique, rather than collecting opinions, hunches, and estimates, obtains a record of specific behaviors from those in the best position to make the necessary observations and evaluations. The collection and tabulation of these observations make it possible to formulate the critical requirements of an activity. A list of critical behaviors provides a sound basis for making inferences as to requirements in terms of aptitudes, training, and other characteristics.*

Flanagan (1954, page 30)

3.8.3 Combination of Case Study and CIT

This section examines the combination of Case Study and CIT to ensure that there is no mismatch between the techniques.

Statements in Yin (2009) support the acceptance of case studies being part of a multi-mode study, it is therefore appropriate to investigate if the approach of combining Case Study and CIT has been established.

There is evidence for the use of Case Study and CIT in combination (e.g. Barrett and Barrett, (2006), Tuuli et al. (2009), Elg et al. (2009)).

- The literature identifies areas in which alignment of project management and research can be considered. In a series of editorials, Bredillet considers the link between research and practice (Bredillet, 2006a, 2006b, 2007a).
- Does CIT allow case studies to be used in a way that then gives the focused research that a positivist paradigm would anticipate?
- Is CIT a quantitative method? – Which text books discuss the technique? (I think one that lists it is a summary of the qualitative methods) – need to ensure there is no mismatch between the use of Case Study and CIT.

Thus, on the principle approach to theory building both positivism and case study take a similar view, and it can be suggested that they are compatible.

Then the next stage is to consider how the question can be developed to meet the criteria of a case study investigation with CIT being used for the detailed investigation.

3.9 Developing theory

3.9.1 Developing Theory from the Case Study investigation

The objective of carrying out the case study investigation was to identify output data that could be used as a stage towards the development of theory.

Eisenhardt (1989) provides a framework for developing theory from case studies. This is discussed below.

3.9.2 Developing Theory from the Critical Incident Technique investigation

Whilst the case study approach provides a methodology that allows industrial investigation to be carried out in the overall context of the research question, there is a need to investigate specific details in order to understand the deviation mechanisms associated with individual task activities. CIT offers a more focused research technique to be used within the case study to investigate specific aspects of the problem area.

3.9.3 Theory development in combined case study and CIT research

This requires the combination of the case study approach and a further technique to support the detailed investigation.

The case study method supports the use of multi-mode approaches to research (Yin, 2009).

This is also combined with the discussion is section 5.4 considering the use of CIT to focus the research on specific task issues that test the overall investigation.

Use of Case Study, CIT, and the combination of the two within organisational and management research, and specifically within project management research?

3.10 Discussion

This chapter considered the philosophical foundations of research and the methodology required to conduct rigorous research that supports theory development. The recognition that philosophy, methodology and the subject being researched have a relationship was discussed. Popper (2002, first published in 1935) and Kuhn (1996) provide the contemporary approaches to this. Kuhn (1996) in particular is relevant as the origin of the concept of the paradigm. Smyth and Morris (2007) presented a model that integrated the various aspects required to progress research. The final elements of figure 4 cover research methodology and research methods, which are examined in chapter five to identify specific fieldwork requirements to support the research object. This broad examination was then focused on project management to consider the research framework required for focused research that would be relevant to improving project performance.

Investigation of research methodology was necessary to relate the foundations of research to project management. This allowed project management to be identified as a sub-field of the management sciences and located on the research spectrum (figure 6), and particularly to recognise the nature of project management as a ‘designed’ process and the need to consider it in the context of the artificial science as discussed by Simon (1996). In the case of the management sciences and the sub-field of project management, Cioffi (2006) identifies the relation to both Kuhn and Simon.

The classification of this research (figure 6) shows the balance between the pure social issues and the process issues, and positions the research. The focus is on the underlying process, and how information is generated to support decision making, as this also relates to the social aspects and influences behaviours of actors. The research spectrum allows the area of research to be positioned. This indicates its location between the extremes of research, whether a pure science approach is appropriate, or a more socially orientated investigation is required. It can be seen that project management research is a sub-set of organisational and business research. This is a broad subject, and located across the spectrum. Consequently research is likely to use a range of research techniques.

The research is investigating project management, it needs to focus on investigating “*the intimate connection with empirical reality*” (Eisenhardt 1989, page 532). This is supported by the development of figure 9 by integration of Meredith (1993), as developed by Albores-Barajas (2006, page 40), and Rook (1986). This offers a methodological process with the advantage of a highly visual illustration of decomposition of the subject to be represented by the left hand side, leading to a research focus at the point, with integration towards general theory on the right hand side.

Starting an activity by defining the ‘end game’ is a fundamental difference that challenges the appropriateness of applying traditional scientific tests to the investigation of project management. This develops the argument that organisational sciences require a different approach to the natural sciences, the key aspect being that subjects, such as project management, are "*invented not found*" (Morris 2013b, page 8) to achieve specific objectives. This is clear in that the first activity of a project is to define the final objectives and deliverables. Gregor (2009) discusses the process of theory building in the artificial sciences, although focusing on IT does state that the principles have broader application. The test is to examine whether an artificial sciences philosophy is appropriate to the management sciences, and in the example of project management. This suggests that the research is at two levels, recognising the issues within the broader discussion on the community paradigm for project management and focusing on tools and techniques that relate to improving project performance.

In conclusion, the initial recognition that led to this chapter was a need to understand where research sat in the range of different research approaches. Understanding the general structure of these options, such that specific research could be located, appeared sensible, but, whilst there is much good literature on the subject of business / management and organisational research, it was not clear how different aspects related. This chapter provides an overview to 'join the dots' of these different aspects in such a way that a range of activities across the range of management and organisational sciences could be considered. Overall linking of the philosophy (this chapter) and fieldwork methodology (discussed in chapter five) is illustrated by Arbnor and Bjerke, (1997, figure 1.8, page 17), figure 11.

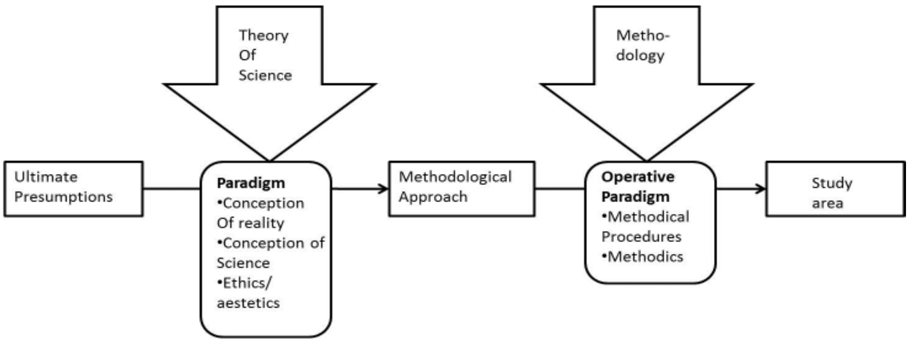


Figure 2.11 Global Methodology (Arbnor & Bjerke 1997)

Figure 11: Global Methodology

Figure 12 integrates the overall methodology presented in figure 9 with the problematisation approach of Alvesson and Sandberg (2011), case study (Yin, 2009) and critical incident technique (Flanagan, 1954).

It is clearly recognised that other literature, across this wide range of activity, is relevant and that there is significant further work to build a more generalised structure that allows management and organisational research to be related to a common frame of reference.

The philosophical and methodological discussion has identified the potential framework of the design sciences on which to position project management. Design science has been shown to have a valid location on the philosophical spectrum and its relevance to the management sciences and sub-field of project management has been recognised by numerous authors. Whilst the discussion in this chapter provides a suggestion of a framework for project management research, more work would be needed to validate this approach. Taking the approach of Davis (1971) and the developments by Alvesson and Sandberg (2011), the approach adopted challenges some of the underlying principles of the subject, which is justified as the current approaches to project management over many years have done little to improve project performance, so an alternative approach may have some merit. This will be reviewed in chapter nine.

Application to project management research and the research focus / research model.

The data collection will relate to a strategy to evaluate the potential benefits of the proposed model by demonstrating it relative to documented data and then developing further examples of data collection as the project develops towards the model being applied to the earlier stages of the project. This will be documented in chapter seven.

The data analysis will then identify approaches that can apply across the collected data and evaluate the potential of the model / process. Analysis will be conducted in chapter eight. How to develop the basic research issue into a structured research activity – relating to the research questions discussed in section 5.5 and ensuring that the fieldwork methodology is consistent.

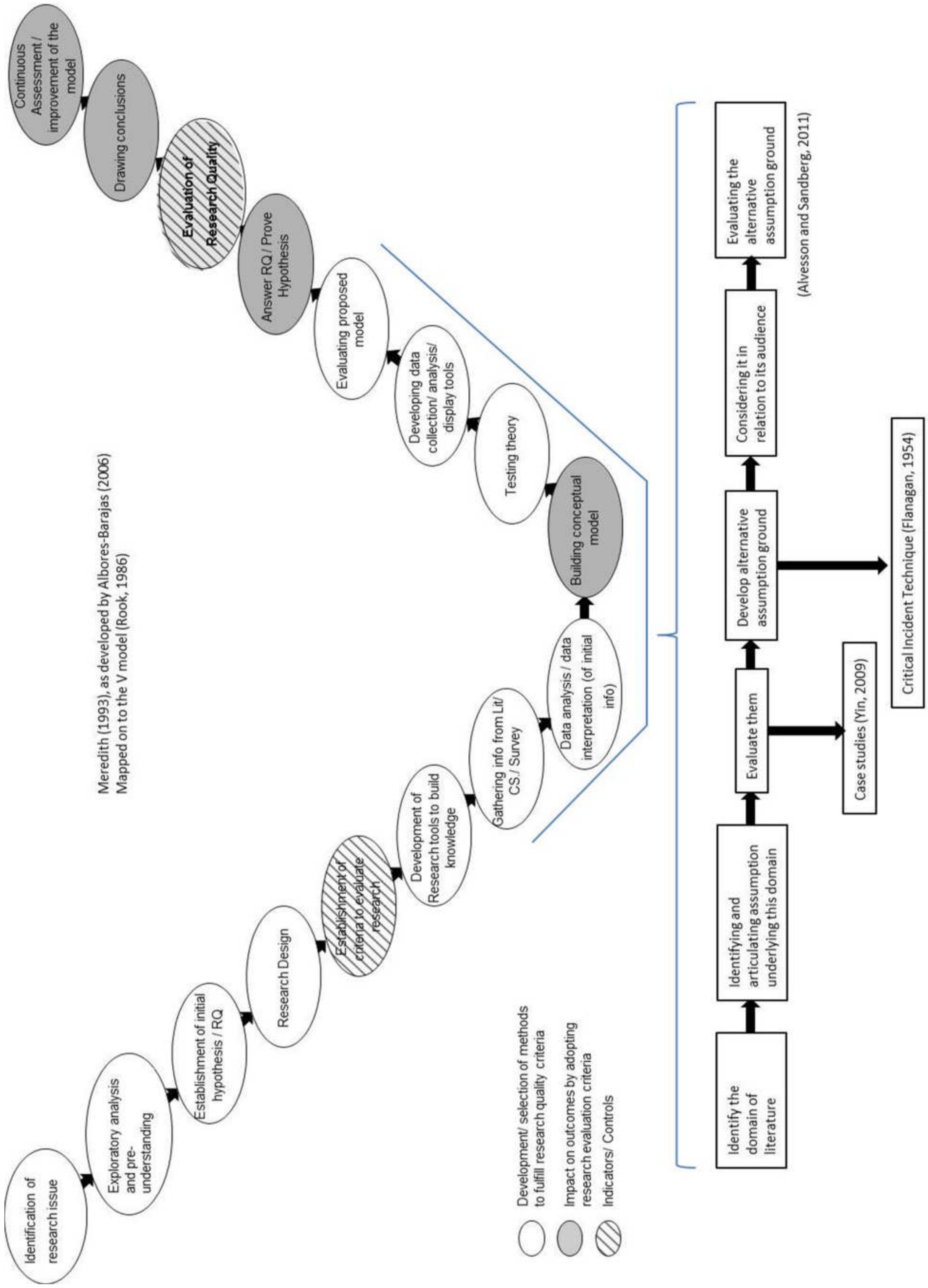


Figure 12: Methodology sequence

4 Development of conceptual model

This chapter investigates the "*Establishment of initial hypothesis or research question*" stage (Albores-Barajas, 2006, page 40), to follow the overall research structure. The objective of this chapter is to develop the research further by focusing on topics that contribute to the development of the community paradigm and reinforce the theoretical foundations.

4.1 Introduction

The "*exploratory analysis and pre-understanding*" (Albores-Barajas, 2006, page 40) discussed in chapter two identified fundamental issues of project management and examined them based on the technique of locating knowledge gaps and research issues. Whilst some direction was identified (focus on process and the key characteristics of improvement), the analysis indicated that some topics do not have a strong theoretical foundation. The key characteristic that emerged was the lack of a community paradigm and consequently the difficulty of identifying knowledge gaps. Without a clear community paradigm the challenge is to define a baseline against which research can be tested. "*Normal science*" (as discussed by Kuhn, 1996) cannot be applied (Bredillet 2010c, page 6). This was recognised in chapter three, by the failed attempt to apply a "*normal science*" approach and identify knowledge gaps from which a focused research issue could be defined.

It is therefore necessary to explore alternative approaches to the subject to identify a suitable baseline and locate the research focus. Davis (1971) argued that an alternative approach to defining knowledge gaps should challenge some (but not all) of the constructs of the discipline.

Alternative approaches are "*identifying anomalies*" (Carlile and Christiansen, 2005) and "*probematisation*" (Alvesson and Sandberg, 2011), as discussed in chapter two. The probelmatization approach was chosen, based on methodology described in Alvesson and Sandberg (2011). As the underlying issue is the lack of community paradigm, the only reasonable approach is challenging assumptions in order to consider the topics relevant to constructing a community paradigm.

Alvesson and Sandberg's (2011, page 256) first stage is to "*identify the domain of literature*". This initial requirement to position and bound the literature review was discussed in section 3.1. The second stage of Alvesson and Sandberg (2011, page 256**)** focuses on *"Identifying and articulating assumption underlying this domain"*. This chapter revisits topics discussed in chapter two considered to contribute to the community paradigm and further narrows the research focus by investigating them to identify and articulate the underlying assumptions, from which a focus can be developed that leads to the research question.

To further narrow the research focus, the third stage of Alvesson and Sandberg (2011, page 257) "*Evaluate them*" is applied to examine the issues and test their relationship to project performance by considering the question: "*What is the theoretical potential of challenging a particular assumption?*" (Alvesson and Sandberg, 2011, page 258). This allows the research question to be developed. The fourth to sixth stages of Alvesson and Sandberg (2011) are discussed in subsequent chapters.

This is summarised in practical terms by Winter et al. (2006):

> *"Herein lies two very important points for developing the field intellectually: firstly, the need to challenge the assumption that the rational deterministic model is an all-encompassing model of projects and project management – as many of the textbooks seem to portray – and secondly, the (often unexamined) assumption that the deterministic model is the actual reality, in other words, the map is the terrain".*
>
> Winter et al. (2006, page 643)

4.2 Future Directions of Project Management Research

Building on the discussion in chapter two (section 2.4), and focusing on the underlying assumptions, this section examines how the literature discussing future research directions guides development of the research question. By testing ‘directions’ the theoretical potential (Alvesson and Sandberg 2011) can be examined and key characteristics can be identified.

The literature identifies multiple directions which correlate to the pre-paradigm nature of the subject. If Bredillet (2010c, page 6) is followed, when a particular view is adopted to allow “normal science” to be applied, the relevant directions will align to a common community paradigm. However, prior to “normal science” being applicable, identifying relevant future directions is challenging. Without a common reference to analyse directions, few conclusions can be drawn. Further analysis of their underlying assumptions is necessary to develop understanding of the key characteristics and their potential alignment to a community paradigm.

The underlying assumption that can be challenged is to examine the role of project management tools and techniques and how they contribute to performance. It is necessary to take an inverse view and examine how tools and techniques lead to performance failure and what action needs to be taken to reduce the potential emergence of performance failure.

From Winter et al. (2006) and related literature (section 3.3, table 1), various future directions topics are identified; ‘*Broader conceptualisation*’ and ‘*Value*’ summarise the overall development of the discipline. These two dimensions direct the overall research and identify the focus on performance. The theoretical potential is to direct development of the community paradigm.

4.3 Project Management: ‘Discipline’ or ‘Field of Study’?

Chapter two (section 2.5) examined whether project management should be considered as a ‘discipline’ or ‘field of study’. Morris (2013a) argues:

> *“I believe that there does need to be, and that there is, a discipline for managing projects; and further, that this discipline needs to be enlarged from how many perceive it today. Doing this will not be*

easy, but the result will be an enormously more useful and relevant body of knowledge".

Morris (2013a, page 6)

If the discipline is emerging, or even if it can be defined, the research challenge is to examine how research relates to the need to enlarge the discipline. Enlargement of the discipline will only occur by challenging the current practices, rather than filling in 'gaps' (if they could be clearly identified). Challenging assumptions and exploring how project management is being applied offers a basis of a way forward and offers more potential to move towards the much needed community paradigm. Gap filling will only reinforce the current view that a community paradigm is needed.

4.4 Theoretical foundation and paradigm of project management

The lack of community paradigm is the underlying reason why knowledge gaps were not identified in chapter three. The need for a community paradigm is the key characteristic required to develop a 'normal science' position for project management. Whilst a full investigation is beyond the scope of this work, suggestions can be offered and the topics examined may be relevant to further work towards this objective. This is considered further in chapter nine.

4.5 Schools of Thought

The various 'schools of thought' (section 3.7, table 3) provide descriptions of project management from different perspectives, which support the view that project management is, at best, in a pre-paradigmatic state, based on the discussion of Kuhn. In order to develop towards an overall theory, or group of theories that operate in a coherent manner. Significant further work would be needed as each school presents its own set of underlying assumptions, making it difficult to align different schools. The potential is to develop a meta-analysis of overall assumptions that contributes towards a broader view of the community paradigm. Whilst this would require significant further work, and is outside the scope of this work, the basic questions are:

- Is there a common epistemology and ontology across the different schools that could provide common ground?
- Do the underlying assumptions of the different schools of thought have any common foundation?
- If their underlying assumptions are challenged, is there potential to develop a common framework to deliver the dimensions of the multiple schools?

The opportunity is to examine if there is a further underlying framework that provides a common basis from which the different features of the schools of thought can be derived.

This also illustrates the problem that was discussed in chapter three that ‘gap-spotting’ is a problem because gaps in which focused research can be located cannot be clearly identified. The ‘gaps’ between topics identified across the different schools of thought are significant, and do not lend themselves to locating focused research issues via ‘gap-spotting’.

The theoretical potential of further investigation in this area is the foundation of a community paradigm and the potential of applying “*normal science*”, allowing research issues to be identified by gap spotting.

4.6 Performance in Industrial Sectors

This section examines how the tools and techniques of project management function in the industrial environment. Identifying the theoretical potential of investigating the industrial sectors requires understanding common features and will provide a generic (towards a discipline independent view) of the application of project management. This will contribute towards a discipline based community paradigm. Ainamo et al. (2010) provides an analysis of the industrial environment in which projects operate. The typical underlying assumptions of project management application in industry is ‘plan the work,

work the plan', assuming that sufficient planning will deliver. Evidence of performance failure suggests that this does not work.

This necessitates deeper investigation to identify the detail assumptions that need to be challenged, and identify how performance failure is identified in practice. Considering the process, the focus is to examine if the tools and techniques provide sufficient information to allow the project manager to comprehend the state of the project and implement action to correct any trend towards the project failing. The area to consider is whether there is a requirement for additional analysis of the projects performance to identify potential failure trends. From a functional perspective, to identify what tools and techniques contribute to industrial performance of project management.

4.7 Project Performance

The objective of this section is to further develop the research focus by examining specific literature that relates to project performance. Following the overall research aim, the underlying issue is to understand how to test projects and recognise potential performance issues that might lead to failures. A growing body of literature, discussed in chapter three and reinforced in the previous section, from multiple industrial disciplines, recognises the impact of unexpected events and deviations. Pinto (2014) suggests that acceptance of deviation is part of the issue. Recognising adverse impact is critical:

> *"When deviations go beyond a certain level, top management must get involved since the decisions may affect delivery time significantly, or at least required unplanned resources to reach the goal".*
>
> Klimstra and Potts (1988, pages 31-33)

This prompts the question: how do you define '*certain levels'* and when, and what, action should be taken?

Therefore investigating the need for action to identify deviations and correct them must be worthwhile, and is discussed across the literature (e.g. Klakegg, 2010). If, however, performance has not improved a different approach is needed. Investigating why methods fail to pick up early warnings could be useful. Taking action to anticipate deviation might also be beneficial.

This should be a factor in the development of the community paradigm and could examine:

- What defines project performance? (and how does it differ from risk management?)
- When projects are failing, what can be done to identify the source of the failure?
- What are the underlying assumptions of the project process that inhibit early recognition of failure?
- Can potential failure be detected earlier in the project lifecycle?
- What supports decision making?

The challenge is to consider what is needed to deliver a project and, in the broad view, examine the interactions with the environment that the project operates in. A first step is identifying project functions and examining them from the perspective of their influence performance and how these functions can be used to detect deviations provides an area of research focus.

4.8 Functions of Project Management

To develop the research focus and question, the research aim identified the need to investigate how tools and techniques emerge from the theoretical foundations. The discussion in chapter three and other issues examined in previous sections of this chapter identify a need to examine the generic performance, independent of specific industrial application. This might be achieved by considering the different roles that project management tools and techniques contribute to overall performance. This can be developed by examining project management as a set of functions and their role in delivering project objectives. This aligns with the research challenge presented on page six by Morris (2000, page 23).

The underlying assumption is that the ‘toolset’ is sufficient; apply the tools and the plan will work. The levels of project failure have been widely documented in literature and discussed in previous sections. They suggest that this is not the case. The assumption should be challenged (as argued by Alvesson and Sandberg, 2011). This is supported by Lawrence and Scanlon (2007) who argue that projects cannot be delivered using 50 year old tools and techniques. Examining this from a functional perspective can assess the completeness of the ‘toolset’ and investigate whether additional functionality is required.

The problem of deviation as a project performance issue was discussed in the previous section. Broad investigation needs to examine how the toolset can be used to predict the emergence of deviation within the ‘open systems’ nature of the project organisation. This examination can also consider if the topics help or hinder the emergence of performance issues. This also contributes to the earlier discussion identifying the lack of predictive measures.

This suggests that research should focus on examining measures that “*do work in practice in some cases and do not in others”* (Hanisch and Wald, 2011 page 4-5) and extend the investigation to consider additional practices that could offer some benefit. This leads to the need to decompose project management and its application across the project lifecycle, from a functional perspective;

> *“The use of tools and techniques is seen here as an indicator of the realities of practice. The study found some aspects of practice to be common across all types of projects and all contexts, but on this background of similar patterns of practice, several statistically significant differences have also been identified.”*
>
> Besner and Hobbs (2008, page 16)

The theoretical potential of investigating the functions is to relate potential process to the requirements of the community paradigm and understand how they contribute to project performance. This provides a global overview of how the project process delivers performance and, therefore, what functionality, if any, is missing.

To consider the common "*aspects of practice*" it is appropriate to investigate the functions that should occur within a project. Shenhar and Dvir (1996) identify functions including *"cost and schedule management, technical management, risk management, conflict and stakeholder's management, life-cycle management"* and *"project management tools for budgeting, monitoring, risk control, and configuration control"* (Shenhar and Dvir, 1996, page 608). Lampel (2001) examines "*core competencies*". Anderson and Merna (2003) identify 11 process based management domains. Browning et al. (2006) examine the activities *"by which products and services are developed";* and include *"project planning (scheduling, budgeting, resource loading, and risk management) and control"* (Browning et al., 2006, page 104). Turner (2006c, 2006d) examines the functions of project management and identifies seventeen 'corollary' statements describing project functions. Based on an extensive survey, Besner and Hobbs (2012) examined the project management toolset and identified 19 items (Besner and Hobbs, 2012, page 19, table 1).

Review of the tools sets and functions identified in literature, and drawing on practical experience, suggests that eleven functions contribute to the structure of the project management process. These are discussed below. This approach aligns with Besner and Hobbs (2012, page 40) philosophy of simplifying the management process due to the reduced number of practices. Some items identified by Besner and Hobbs (2012) could be combined (project management software) or are not included in this analysis (e.g. Multi-project management) which focuses on the task, work package or individual project level.

1. Time base / Lifecycle Management

Three topics might be considered within this function: Planning, for which significant literature exists (for example: Bruni et al. (2009), Blyth et al. (2004), Herroelen (2005), Herroelen and Leus (2005)), identify Progress Reporting and Review. Morris suggests that the distinguishing factor is the project lifecycle (Morris, 2000; 2013a, page 116);

"If the only thing that really distinguishes projects from non-projects is the project life cycle, then the discipline must be generically applicable to the management of all projects, whatever their type".

(Morris 2000, page 3)

If the project lifecycle and the constraints on delivering objectives are the features differentiating projects from normal business (sometimes described as 'operations'), then there is now a process, the project lifecycle model, that offers the basis on which project performance might be measured. Success of the life cycle model in delivering objectives, within the defined delivery constraints could provide a test of performance.

2. Cost Management

The main cost management reporting technique is EVM. Significant literature analyses this area, and examines EVM performance (e.g. Eden et al., 2005).

3. Requirements

Defining the requirements is the fundamental basis on which all activities to plan and deliver the project are based. Whilst this has to be a first stage, it is also the stage where the least knowledge of the project exists, so is likely to be the point from which changes to the project scope and objectives are likely to originate.

Requirements may originate from a number of sources; e.g. Product, Process or Stakeholders. Relevant literature is: e.g. Ning et al. (2005), Achterkamp and Vos (2008), Zickert and Beck (2013).

4. Risk management

Risk management may have been a relatively recent introduction: Kozak-Holland (2011) suggests that it was introduced to the PMIBok in 1983, but recognises that risk management, via the insurance industry, has been practiced for several thousand years. It has only recently been introduced to project management process models such as 'PRINCE2' [PRINCE2, 2005]; at previous issues it was specifically excluded. Vast literature is applicable; e.g. Williams, (1996); Kutsch and Hall, (2005); Jaafari, (2001); Flyvbjerg (2006). Whilst well established procedures are applied for risk management. Nikander and Eloranta examine the process and suggest "*risk analysis often remains a one-time procedure at the beginning of the project with very little true risk management being carried out during the course of the project*" (Nikander and Eloranta (2001, page 386).

'Uncertainty' is a different aspect, Atkinson et al. (2006) suggest it originating from the inherent issues within the project structure, its goals, organisation and the interpersonal effects of groups of people involved in delivery process, and the ways in which these evolve over the project lifecycle (Klakegg, 2010, page 28).

It might be suggested that the difference is that 'Risk' examines the more strategic and external issues that could impact progress and 'Uncertainty' examines the more tactical and internal issues.

5. Resources

Resources can be identified in three 'breakdown structures': Product, Organisational and Work.

6. Change Management

Change is a fundamental function of projects, and its management is critical. (E.g. Jarrett et al. (2011), Boddy and Macbeth (2000)). Based on a study of 448 projects, Dvir and Lechler identified:

> *"If we add the total effects of goal changes and plan changes on project success, their combined effect is considerably stronger than that of the quality of planning".*
>
> Dvir and Lechler (2004, page 1)

Therefore, it might be argued that understanding the change process, and examining how it can be managed to reduce or control the impact of changes, would provide a useful contribution to improving project performance.

One approach would be to analyse the planned activities and identify any potential performance issues, potentially predicting deviations and applying a contingency plan.

7. Configuration Control

The role of configuration control is tracking output and ensuring it meets requirements and managing configuration changes including identification of requirements that are not met.

8. Validation and Verification / exit criteria

Identification of requirements that have been met – and what evidence is required to demonstrate conformance.

Definition, and agreement with project sponsor of the criteria by which it is demonstrated that requirements have been met, and that work on delivering the specific objectives can be terminated.

9. Delivery

Handover of the project objectives to the customer and transition to ‘in-service’ phase.

10. In-service

For an overall analysis of projects and for service projects that include the in service phase, it is necessary to examine this area. In general the primary activity will be the maintenance of a service contract, or service level agreement.

11. Closure

This will cover stakeholder exit strategy and the final closure of the project.

Integration of functions

These functions need to operate in an integrated and coherent manner to deliver project objectives. Based on the general literature review and industrial experience, figure 13 illustrates a possible process model.

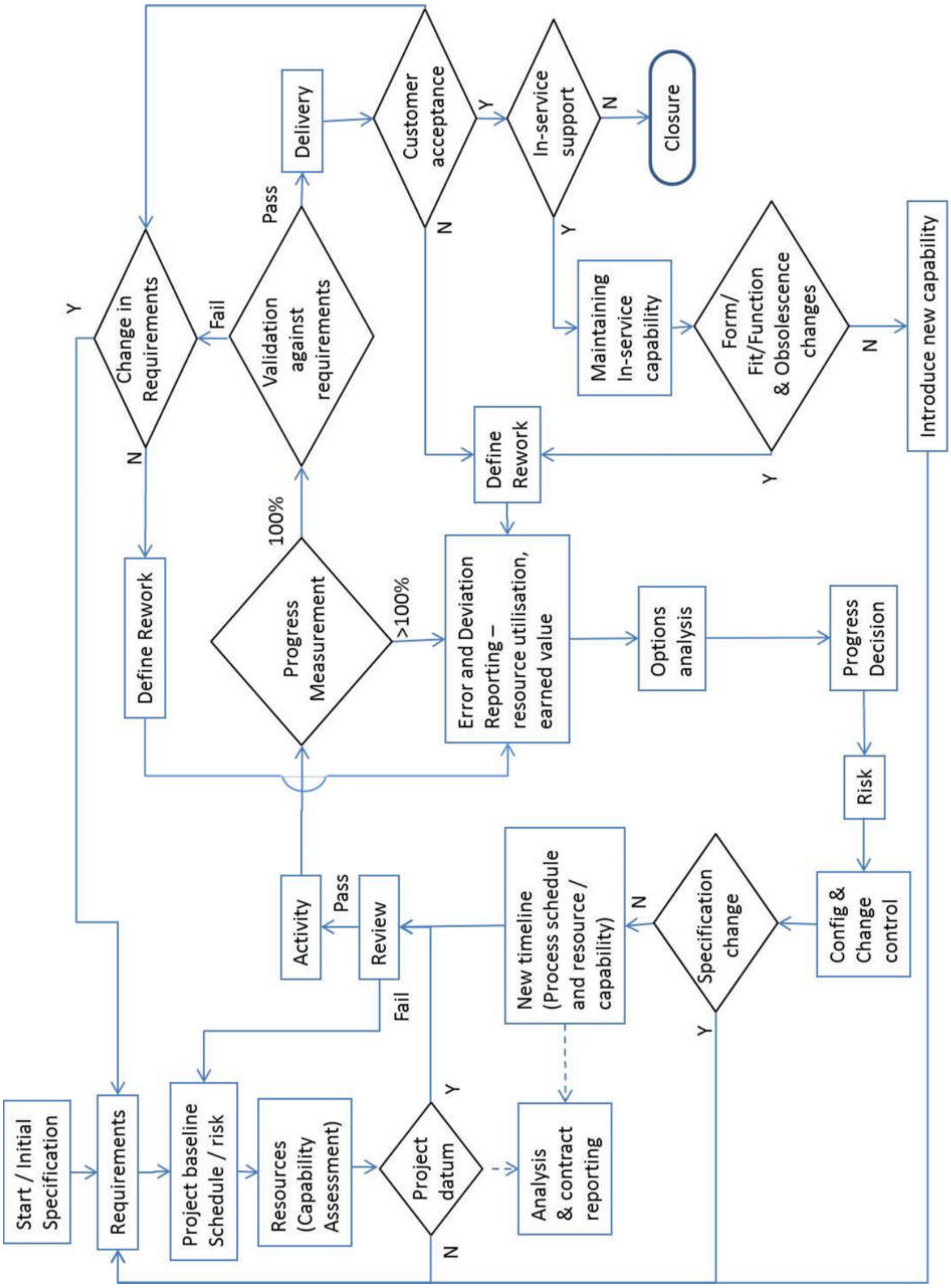


Figure 13: Functional process integration

Discussion

The purpose of examining the project functions was to establish whether they provided a full ‘toolset’ to deliver a project, or whether alternative of additional functions were required.

Whilst planning for success is ideal, experience recognises the need to challenge the potential of the project plan to deliver the required performance. The typical toolset discussed above, and the potential integrated process in figure 13, suggest that none of the functions actively test the plan, or its progress, for performance.

A development of the functional approach would be to consider project activities in the context of ‘capabilities’, as discussed by Bannerman (2013). This could apply the positive learning capabilities as well as negative capabilities. This is considered in chapter nine as further work.

4.9 Project Management Research Questions

The examination in the earlier chapters supports the functional view, and provides a broad assessment of the issues and context for the research aim and focus for the research question.

The research to this point can be summarised:

1) Projects are a sub-field of the management sciences and exist in a broader structure of portfolios and programmes they have a specific role within this structure. (Section 2.3).
2) Projects provide the strategic context to achieving objectives – and should be focused on the overall governance of a task network, the definition and delivery of a set of requirements – they are open systems that need to respond to their environment and changes that occur. (Section 2.3).
3) Projects utilise a common function set, (tools, techniques as presented in text books and bodies of knowledge, that form the underlying basis of project management as a discipline), which are then tailored by industry

or project specific processes that account for the ‘one-size-does-not-fit-all’ argument. (Section 4.8).

4) Tasks focus on the detail delivery of individual requirements (or small groups of closely related requirements).
5) Deviation originates in the tasks, influenced by antecedent variables (Section 2.10) – therefore overall project performance will emerge from the summation of individual task performance.
6) Analysis of task performance and early detection of deviations, with appropriate corrective action, will contribute to improvements in project delivery performance.

Predictive action that minimises deviations and their consequences must be beneficial to improving project delivery performance. Therefore predicting deviation is a reasonable research topic. Research needs to recognise:

- The lack of community paradigm
- The need to challenge assumptions
- Collective approach to project management as a function set
- Examination of generic functions and which ones contribute to performance improvement (this challenges some, but not all, of the underlying assumptions of the subject).
- Prediction is not identified as a project function.

This suggests that the investigation of the research aim might benefit from examining the mechanisms of the project lifecycle, and how the potential performance could be tested.

This activity will need to occur during the planning and early execution stages.

- Which functions contribute to early detection of project failures?
- Is a “performance prediction” function needed?

Parsons (2006) identifies metrics that are analysed to provide an interim performance metric for projects. This is useful to provide a confidence check of progress between the major design reviews defined in the project lifecycle.

Referenced by Parsons (2006), Hughes et al. (2004) suggests assessing projects on several factors at the beginning of the project.

The specific location of the research needs to be clarified. In addition to specific reviews at planned stages of the project lifecycle, Parsons (2006) argues the need for interim measures of project performance:

> *"All projects would benefit from objective predictive measures early in the lifecycle when corrective action can be achieved"*
>
> Parsons (2006, page 11)

This prompts an examination of aspects of the project management toolset that might provide interim performance measures and which ones provide "*objective predictive measures*"?

> *"[…] the literature reveals no previous studies using an objective interim measure of project performance. In fact, the literature is virtually silent on suggested appropriate metrics to measure interim project performance".*
>
> Parsons (2006, page 11)

None of the tools focus on 'deviation' or prediction of performance issues. None examine what actions should be taken (Consider the previous discussion on deviations and exceeding 'certain levels' (Klimstra and Potts 1988, page 31 – 33), How does the toolset support identification of the deviation issue and what and when action should be taken?)

These performance metrics can be focused on project performance failures as generic reasons why projects do not go to plan, or why they deviate. Hällgren (2009) provides an initial study "*that contributes to the understanding of how unexpected events (deviations) are handled*" (Hällgren, 2009, page 611) Hällgren and Maaninen-Olsson (2009) identify the need; *"Since deviations will inevitably occur and they will substantially increase project costs, studies of them are imperative"* (Hällgren and Maaninen-Olsson, 2009, page 53).

Hällgren (2009) identifies the term 'deviations' to describe project behaviours that do not conform to the desired intent. In table four, a thesaurus search was conducted on the term 'deviation' and the alternatives identified were used as terms for a scopus search to identify relevant literature. The combination of "project management" and each of the terms e.g. "project management" AND "divergence". The results of this analysis are in table four. This suggests relevant literature exists on the concept of deviation within the project environment.

Table 6: Alternative search phrases

Alternative term (from Thesaurus search)	Scopus search phrase Project management AND *"term"* e.g. 'project management' AND 'divergence'
Divergence	360
Departure	245
Difference	7,736
Variation	3,440
Digression	3
Change	22,576
Movement away	2
Nonconformity	9
Non-conformity	18
Aberration	0
Abnormality	74
Deviance	98
Deviation	1,034

There is a need to predict future conditions – or at least the potential options and consider the contingency that may need to be applied, and consider the criteria that control the decision to take action. This needs to be developed to provide a basis for research focus.

4.9.1 Research question

Summarising the previous discussion, the literature review identified a range of issues, most significantly, the lack of community paradigm. This required an approach other than gap spotting to identify a focused research topic. Problematisation (Alvesson and Sandberg, 2011) suggested challenging underlying assumptions. This approach led to a functional analysis which identified performance prediction as a missing function. Performance failures may be regarded as issues that cause deviation from planned activities. Based on this, the research question is:

> How can predicting task deviation positively influence improved project performance?

4.10 Initial process model

To start to examine the research question, the first concern is to consider the modelling of deviations. The basis of developing a model requires an initial understanding of the process to be tested.

Tasks can deviate from plan, corrective action is required, and needs to be embodied in a manner that allows the original objectives to be achieved. – Statement of the original problem, or hypothesis.

Bannerman (2013) identified '*antecedent variables*' and noted: "*Managing these variables to improve their fit and application to IS/IT projects has been found to have performance improvement effects*" (Bannerman, 2013, page 4325).

The issue of deviation can be illustrated. A task might be ideally represented as a timeline from start criteria to finish criteria.

The initial concern is to represent the ideal task progression, figure 14.

Figure 14: Theoretical task model

This can be developed to represent the occurrence of a deviation and its corrective action. In figure 15 it is suggested that initially the task remains close to plan, but as time progresses a deviation emerges, the progress of the task is further away from baseline. If appropriate corrective action is applied, the task might still be delivered to plan, but is likely to be late and over budget. In effect, the area under the curve represents the deviation from plan which could be equated to resource and cost / schedule over-run.

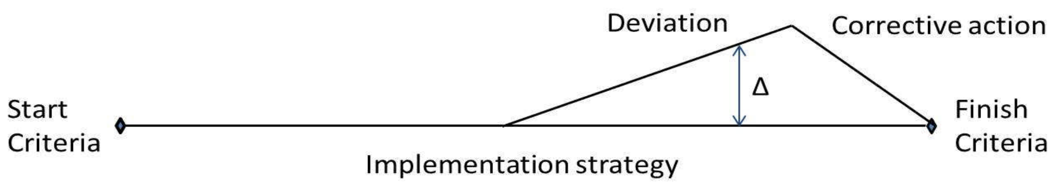


Figure 15: Theoretical task model with deviation

Hällgren's work concentrates on managing the deviation once it has emerged and can be clearly defined.

The development of the research focus is to ask what happens in the early stages of the task. Can any process be applied or action taken that would minimise, or even eliminate, the occurrence of the deviation, such that the task remained much closer to plan with reduced impact on resources?

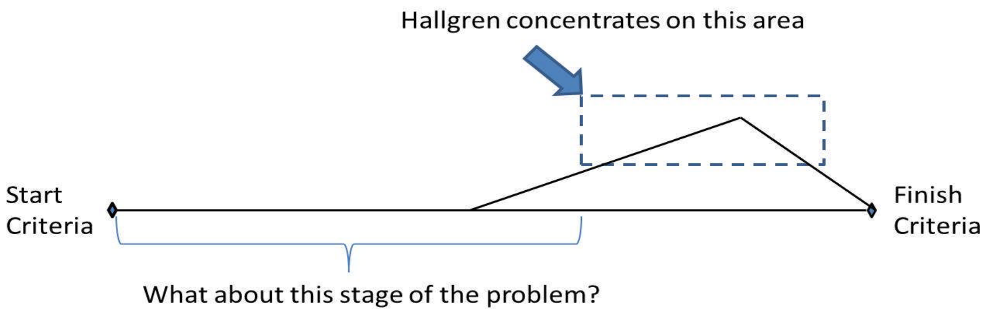


Figure 16: Research focus

Thus, the research can be focused to examine the prediction and detection of early stage deviation. This could be investigated by examining early warnings and weak signals (WS). The identification of potential deviations (in individual tasks) and their early detection, combined with the opportunity to plan and implement a mitigation strategy, may offset their adverse impact and contribute (when applied across the task network) to improved project performance.

Nikander and Eloranta (1997) identify the work of Ansoff (1975) and challenge the possibility that WS exist in project organisations. They suggest that; *"There are also messages which can be interpreted to be preliminary warning signals. The research analyses the character of the signals, their appearance, what project problems they are related to, and what their basic reasons are"* (Nikander and Eloranta, 1997, page 371).

Nikander (2002) identifies the need for further research to "*address the questions left open by the present study"* some of which align to the focus of this research and challenge the need for deeper understanding WS and their occurrence. These topics provide a focus to investigate the research aim and research question.

4.11 Develop the research model

Following the topics within Albores-Barajas (2006), this chapter focuses on "*Gathering information from Literature / Case Study / Survey*" (Albores-Barajas, 2006, page 40) and "*Data analysis and data interpretation of initial information*" (Albores-Barajas, 2006, page 40).

"*Building the conceptual model*" (Albores-Barajas, 2006, page 40). This examines the theoretical model and its industrial application. This supports the fourth stage of Alvesson and Sandberg (2011) – "*develop alternative assumption ground*". The fifth and sixth stages of Alvesson and Sandberg (2011) are discussed in subsequent chapters.

This section investigates the research question derived in chapter four by developing a theoretical model and practice method to predict task deviation and apply mitigation. The research model addresses the problem of "*objective predictive measures*" (Parsons, 2006, page 11).

This need can be considered in the context of typical deviation cases. For example, little early action can be taken on cost increases, other than the continuous pressure to keep costs down. Cost increases impact the project when they occur, but can be anticipated and contingency planned. When a cost increase is identified then the tipping point has occurred and the contingency is applied. Alternatively, it may be acceptable to allow a task schedule to extend if it has no immediate impact, but a mitigation plan needs to be available to implement if the schedule extension is likely to impact the critical path. This mitigation will only be implemented under specific conditions, and may not be needed if the task is completed.

There is therefore a need for methodology that offers the opportunity to identify the issue, define the mitigation and application criteria. This will have the objective of contributing to developing methodology to guide practitioners in assessment of detailed analysis and structure required to achieve improved project performance. This will be achieved by investigating issues underlying project failure and conducting research that targets failure sources and detection techniques.

4.12 Research model

The need to investigate deviations is identified by Hällgren and Maaninen-Olsson (2009, page 54). Developing the representation of the problem discussed in chapter four is considered in three sections:

1: Literature review on the subject of early stage recognition of issues

2: Develop a theoretical model to represent the problem in practice.

3: Develop a process that can be tested in an industrial environment.

4.12.1 Literature model

Literature review identifies different aspects of prediction and the initial conditions that may lead to deviation. Liu et al. (2010) focus on task completion competency and examine the influence of functions that exist outside of the specific task (figure 17). This indicates that the broader operating environment of the task must be accommodated, and that the outcome of the task may have a dependency on functions that influence the initial start and ongoing conduct of the task.

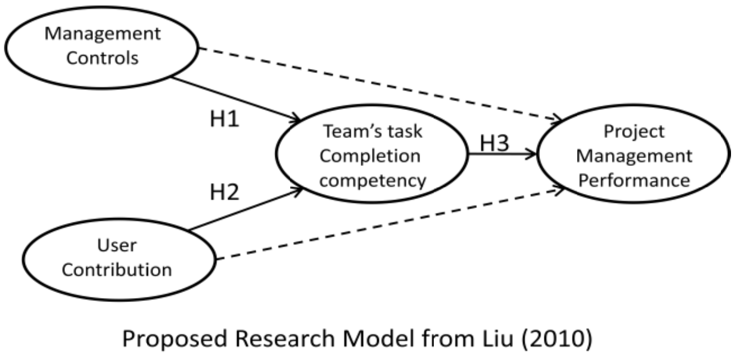


Figure 17: Research model (Liu et al., 2010)

This provides the context of understanding project performance, as discussed by Aladwani (2002), figure 18.

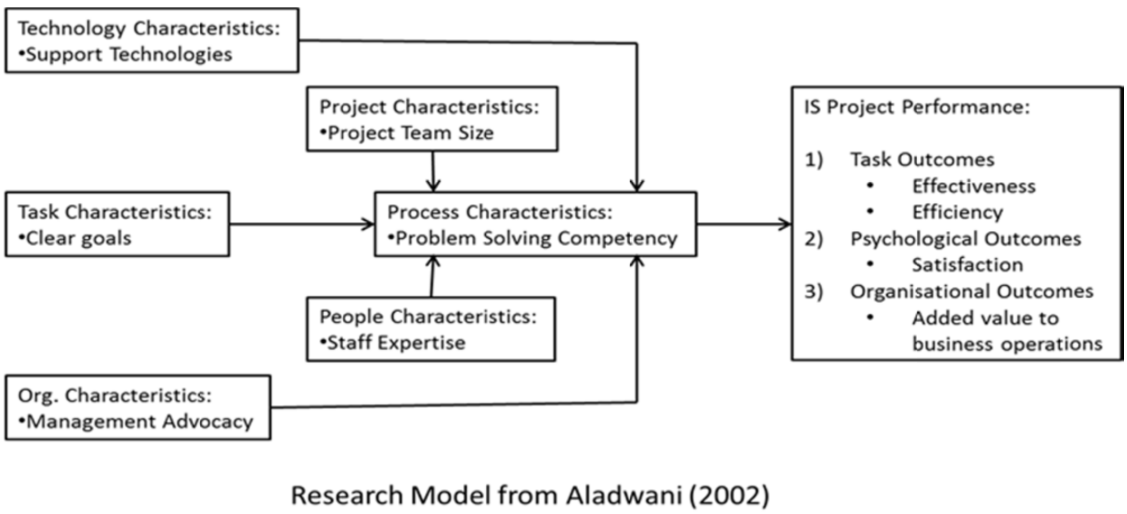


Figure 18: Research model (Aladwani, 2002)

Busby and Hughes (2004) identify pathogens and incubation processes.

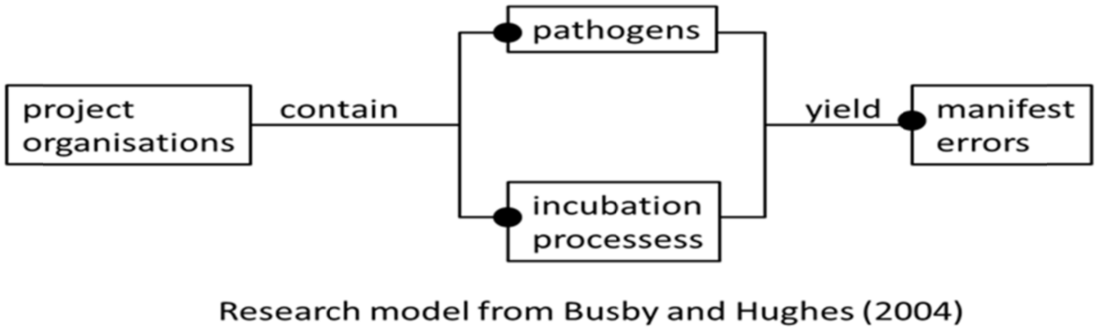


Figure 19: Research model (Busby and Hughes, 2004)

This can be expanded to consider whether there are other factors that might be defined as antecedent contributors to task deviation. The main categories of pathogen are given by Busby and Hughes (2004) in table seven. They also suggest that detailed sub-categories for pathogens are applicable, but only those arising from ‘practices’ are listed in their paper. Therefore, it is impractical to investigate the sub-categories of all the pathogens identified in table seven.

Table 7: The main categories of pathogen

Category	Description	Example
Practice	Pathogens arising from peoples deliberate practices	It was the practice for designs to be checked only for internal consistency not consistency with external constraints and requirements.
Task	Pathogens arising from the nature of the task being performed	Trace quantities of a contaminant had disproportionate consequences in a particular process design task
Circumstance	Pathogens arising from the situation or environment the project was operating in.	Firm procured services in a market where there was inadequate information about the quality of products
Convention	Pathogens arising from conventions, standards, routines and codes of practice	A person adhered to a company standard that had previously always been superseded by ad hoc agreements – which as a result had unknowingly become obsolescent
Organisation	Pathogens arising from organisational structure or operation	Slow ramp-up of projects led to delay in early tasks on which many others were dependent for information, and which therefore had to proceed on tentative assumptions
System	Pathogens arising from an organisational system	Latency in a change control system meant that a significant amount of engineering information being used was obsolescent
Industry	Pathogens arising from some structural property of the industry	Public contracting regulations required that the firm consider vendors of whom they had no direct experience
Tool	Pathogens arising from characteristic of a technical tool	A design tool provided a layering facility that encouraged people to simplify their tasks but allowed them to forget possible inconsistencies with other parts of the design

(Simplified from: Busby and Hughes (2004), table 1)

Incubation processes are also identified by Busby and Hughes (2004) in table eight.

Table 8: Incubation process

Category	Description	Example
Chance	Accumulating probability of some occurrence	Accumulating probability of a locally optimised design being unable to accommodate change and uncertainty
Stress	Accumulating pressure on some resource or aspect of performance	Accumulating lead-time pressure leads to increasing concurrency and increasing vulnerability to tacit assumptions
Habituation	Accumulating habit of acting in some particular way	Accumulating habituation to a size of equipment not needing analysis and accumulating confidence there is no scaling effect
Quantity	Accumulating quantity of some entity that has to be managed	Accumulating numbers of items in change control pipelines that should keep systems consistent
Reinforcement	Accumulating trend of some kind that is self-reinforcing	Accumulating encroachment on safety margins as these margins deny feedback on proximity to failure yet confidence increases with each design
Obsolescence	Accumulating divergence of some knowledge from reality	Accumulating loss of collective memory of the rationale of designs being reused
Complexity	Accumulating inter-connections and inter-dependencies in some system	Accumulating complexity of design which meant increasing number of tasks in which interruptions could render the design inconsistent

(Simplified from: Busby and Hughes (2004), table 3)

The combination of a pathogen and incubation period represents the early stages of a deviation. If either of these, or their combination, can be detected at an early stage there is potential to apply mitigation and reduce the adverse impact of the deviation maturing. It is reasonable to work at the levels described by tables seven and eight.

The initial approach would be to reference to the list of pathogens given by Busby and Hughes (2004) and then investigate whether there is evidence of their existence within the selected case studies. The second aspect is to consider ‘incubation periods’ which are periods during which a ‘pathogen’ is present in an activity, but not recognised as causing a problem. Can the incubation periods of pathogens be identified in the industrial applications?

Integration of literature models

Is there evidence that the pathogens originate in the 'antecedents' of tasks as described by Liu et al. (2010)?

A focused investigation can be developed using Busby and Hughes (2004) discussion and definition of 'pathogens'. Can evidence be identified such that the initial conditions can be identified to allow tasks to be conducted in a manner that supports improved project performance? How does the identification of pathogens, and their subsequent resolution, support improvements in the overall project delivery performance – does the detection and resolution of pathogens support the integrated framework discussed by Aladwani (2002)?

The approach adopted for this work is to argue that the underlying requirement for a project from either the social perspective or the technical perspective, as defined in Aladwani (2002), is the quality of information that supports the decision making processes required to maintain project progress.

The research models identified in the literature all provide a contribution to describing the underlying process of the emergence of deviations. Initial identification is clearly important, but the process of correction and resolution is critical in practice. Therefore there is the need for an integrated model that tests the initial conditions and allows the overall benefit to be realised, i.e. the resolution of the deviation with minimal adverse impact on the task. Figure 20 proposes the integration of the literature models previously identified.

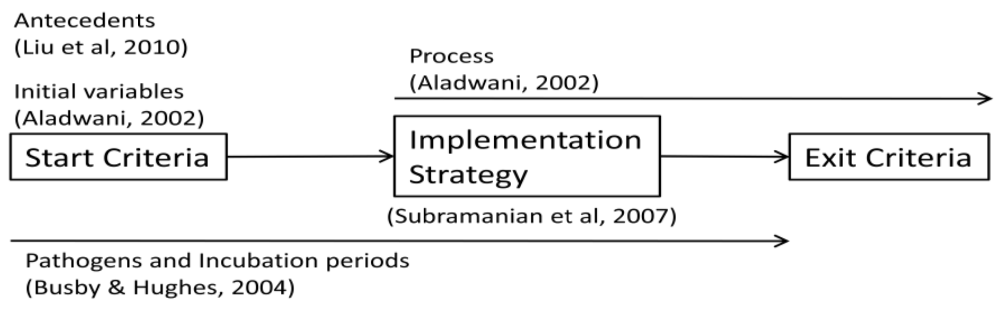


Figure 20: Integrated literature model

This integration of the literature models can be described as a "Deviation Lifecycle". The key characteristic is that this describes an overall process from the early stages through discovery and correction. This builds on the functional description of the project considered in chapter four by adding a functional model of the deviation process.

Extending the analysis of alternative phrases (Table four, Chapter three), a further literature search was conducted to examine the terms in conjunction and combination with "lifecycle", table nine.

- Search 1 – searched for combination of each term and 'lifecycle' e.g. "divergence" AND "lifecycle".
- Search 2 – combined the terms into a single search phrase '*term*' + lifecycle e.g. "divergence lifecycle".

Table 9: Search terms

Alternative term (from Thesaurus search)	Scopus search phrase	
	"*term*" AND life cycle e.g. 'divergence' AND 'lifecycle'	"*term* lifecycle" e.g. 'divergence lifecycle'
Divergence	320	1
Departure	87	0
Difference	3,876	0
Variation	2,818	0
Digression	1	0
Change	11,010	13
Movement away	0	0
Nonconformity	11	0
Non-conformity	4	0
Aberration	0	0
Abnormality	154	0
Deviance	47	0
Deviation	324	0

This did not identify any significant literature, and suggests that this is an area that has yet to be researched. 'Change' being the exception, however change management is a significant research area in its own right. A managed change process is different to detection of emerging unplanned deviation.

4.12.2 Theoretical model

Having examined the literature, the second activity identified in the chapter introduction was to develop the deviation lifecycle theoretical model to represent the problem in practice. This can be termed: Deviation Lifecycle – Theoretical Model (DLC-TM).

Figure 21 allows the key characteristics of the research topic, as identified in the literature model to be mapped. The presence of antecedents (Liu et al. 2010) as the initial source of a deviation, and the point through the task progression at which a deviation might be triggered are shown in figure 22.

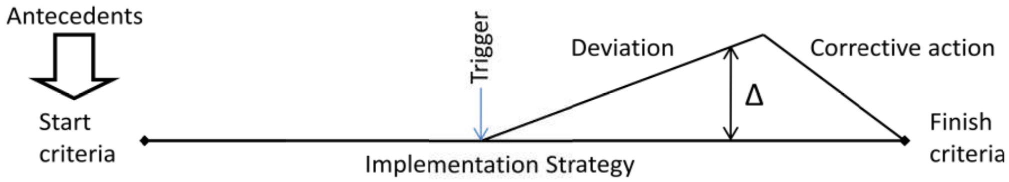


Figure 21: Task model

This allows the pathogen-incubation process (Busby and Hughes, 2004) to be applied, figure 22.

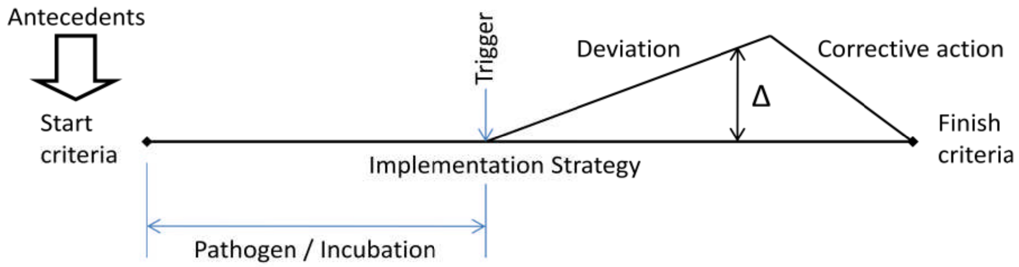


Figure 22: Task model

The typical practitioner process can be mapped onto the model. There is some time delay after a deviation is triggered prior to its discovery, after which a solution is defined. During the time the solution is being defined, the deviation may increase in magnitude. Only when the corrective action solution is implemented might the magnitude of the deviation reduce, ideally to achieve the task finish criteria. Activities taken prior to discovery of the deviation might be considered proactive, whereas those taken after are reactive. This is illustrated in figure 23.

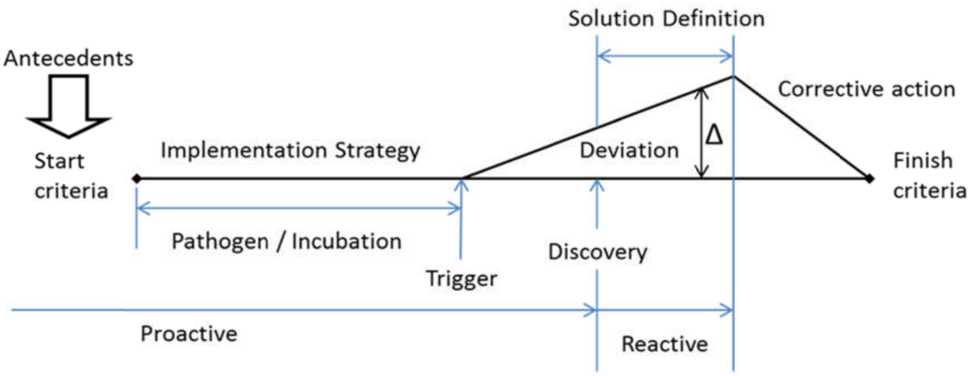


Figure 23: Deviation Lifecycle-Theoretical Model (DLC-TM)

To tackle the early stages of the deviation lifecycle, ideally to resolve issues by removing pathogens during the incubation period, action needs to be applied during the proactive stages of the process model. This focuses the next stage on considering how the theoretical model can be tested to identify the potential for deviation and to define the mitigation plan.

This requires application of an analysis technique that can be applied ‘before the event’ to test the potential for failure. This needs to be followed by a technique to examine the occurrence of the deviation and to define when the mitigation plan should be implemented.

In effect, if the ideal delivery of the task is represented by the straight line between the start criteria and the finish criteria and deviation is represented by moving away from the straight line, then the challenge is to investigate why movement away from the straight line occurs, and to understand how to stay on the straight line for a larger part, and preferably all, of the task lifecycle.

4.12.3 Industrial method

The challenge now is to investigate how the theoretical model (DLC-TM) could be developed into an industrial process and applied in practice. The key requirement is to establish a suitable mechanism to examine the potential for failure pathogens to be present in the early stages of the deviation lifecycle.

Consideration of these requirements suggested three techniques could be combined:

- Failure modes and effects analysis (FMEA)
- Weak signals (WS)
- Tipping point analysis (TP)

Failure Modes and Effects Analysis (FMEA)

Review of techniques that focus on the period prior to commencing task work, FMEA offers a potential solution. Whilst initially developed to identify product failure modes, it has been applied successfully to process analysis, and in this case could be applied to test the potential of a task to deliver to plan. FMEA has been applied in a project context, for example, Souza dos Santos and Cabral (2008).

Teng and Ho (1996) describe the FMEA process. Traditionally used for product design analysis, FMEA is a successful and widely accepted standard tool. It has been applied to process and could also be used to develop confidence in the management processes and their potential to deliver. Industrial experience of using FMEA recognised that it was applied during the early stages of a development project and this prompted the potential for application to predicting deviations. Teng and Ho (1996) include discussion on link to ‘design’ FMEA and ‘process’ FMEA. Application in this research examines the application of FMEA to cases where tasks deviate from plan, which is equivalent to them failing to deliver the expected performance (i.e. project performance), and extends the application of FMEA to performance. Hällgren and Maaninen-Olsson (2009, page 56) identify different practice concepts that support the argument, although FMEA has not been applied to analyse ‘performance’, this research model extends the application.

To apply FMEA, it is necessary to identify topics to examine. For the purposes of the research, success criteria identified from literature review can be employed to illustrate the potential of the research model. Clarke (1999) examines the use of success factors in project management.

Success criteria

Tishler et al. (1996) identified some 400 managerial variables for their influence on project success. Further literature review identified various criteria, resulting in 17 ‘success factors’ summarised in appendix A, and used to provide a common baseline for analysis across the case studies. These are suggested criteria; practical application could use a different set.

The selection of criteria for FMEA was intended to provide a common baseline to test the different case studies. I.e. use of the same set of criteria to test all the case studies in order to allow discussion between them to examine the application of DLC-IM (figure 24) and its relevance to detecting deviations and determining mitigation. These are considered reasonable for illustrative purpose. This application extends the potential of FMEA to test performance.

Other techniques such as pareto analysis or Ishikawa diagrams could be investigated to identify potential topics. The critical issue is that there is a set of common criteria to be applied to the industrial analysis.

Weak Signals (WS)

Introduced by Ansoff (1975), and reviewed by Rossel (2011, 2012) and Holopainen and Toivonen (2012), the concept of WS theory is that evidence of future state is present at an early stage, prior to an ‘issue’ emerging as a clear entity. This has been examined in a number of fields with some success. Nikander and Eloranta (1997, 2001) and Nikander (2002) investigated early warnings in relation to project management and provides a full review of the background theory. Nikander and Eloranta’s work focused on the ‘project’ (Nikander and Eloranta, 2001, figure 1, page 389) as the unit of analysis.

Tipping point (TP) analysis

TP analysis may provide a mechanism to apply judgement / metrics to the decision when a potential deviation is likely to become critical and impact the project.

Taylor and Ford (2006) discuss TP failure in projects – their abstract states: "*Tipping point feedback structures can push a series of product development projects into firefighting mode in which re-work overwhelms progress*" (Taylor and Ford, 2006, page 51). This is a good description of precisely the situation this research is attempting to contribute to avoiding. If it is practical to identify the point at which a deviation would move from being relatively insignificant to causing re-work that would impact the task delivery, then a criteria might be identified that can be used in conjunction with the WS analysis to construct a monitoring framework that can identify when corrective action should be applied.

This allows the project manager to observe the early stages of deviation and monitor the project status for these criteria occurring, prompting corrective action to be applied. Whilst the higher RPN values would attract the initial interest, the analysis of WS might indicate a situation that requires immediate attention or one that can be responded to when specific situations arise.

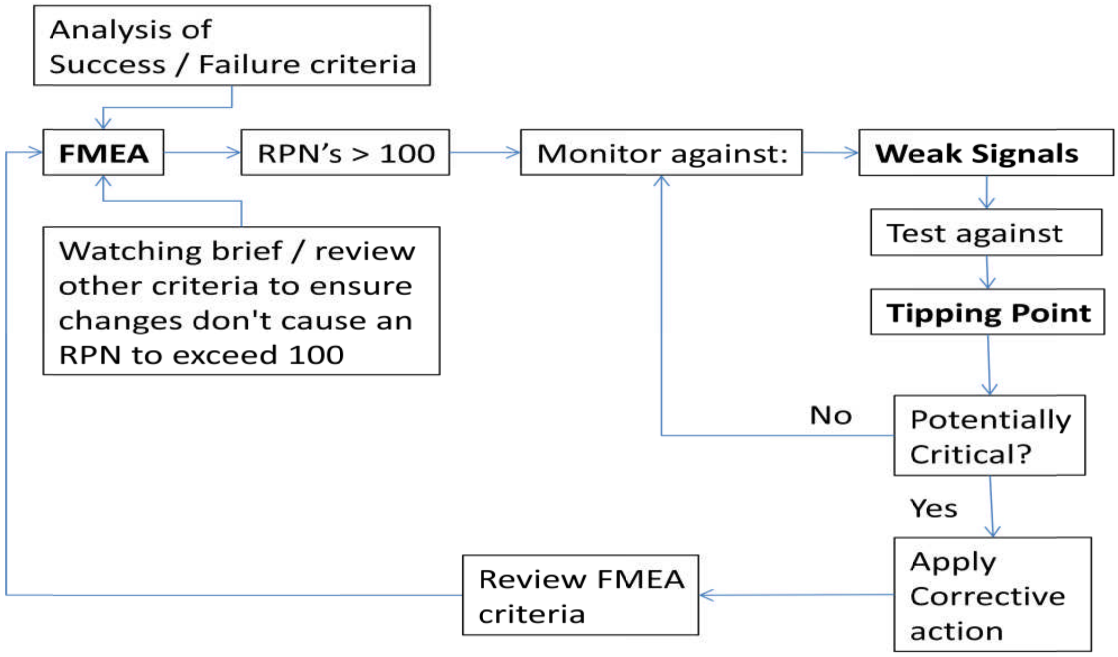


Figure 24: Deviation Lifecycle – Industrial Model (DLC-IM)

4.13 Discussion

This requires identification of independent and dependent variables and establishing the cause and effect relationship between them. This can only be achieved in a scientific sense if there is a theoretical foundation against which the investigation is tested. The issues discussed in this chapter and chapter three suggest that this is a fundamental problem.

The discussion presented in chapters 3 and 4 covered 2 key dimensions: recognised the lack of community paradigm and investigated topics relevant to the development of a community paradigm.

Without a recognised community paradigm it was clearly shown in chapter three that gap spotting (and its dependence on the accepted theoretical foundation, i.e. the community paradigm) would not challenge the foundation of project management or lead to relevant research questions that result in contribution.

"*Problematization*" based on Alvesson and Sandberg (2011) has attempted to challenge assumptions and identify topics that relate to a potential critical path and therefore relevant research issue and research question.

This led to the view that a function analysis of project management would examine the subject from a non-industry specific perspective and identify contributors and inhibitors of project performance.

It was concluded that there was little evidence of project plans being tested for their potential to deliver the required performance. Consequently, examining the project for evidence of deviations, and their early detection could contribute to developing methodology to guide practitioners in assessment of detailed analysis and structure required to achieve improved project performance.

There are two dimensions to be considered in the development of methodology to guide practitioners, firstly to identify the potential of a deviation and its early detection and secondly to decide what, and when, any mitigation is required.

Focusing on early stage deviation detection could support the aim of investigating issues underlying project failure and conducting research that targets failure sources and detection techniques, and therefore fulfil the research question.

5 Industrial investigation

The objective for the industrial investigation is to examine the potential for practice application of the research model to support improving project performance. This applies the "*testing theory*" stages of (Albores-Barajas, 2006, page 40).

- *"Developing data collection / analysis / display tools"* (Albores-Barajas, 2006, page 40)
- *"Evaluating proposed model"* (Albores-Barajas, 2006, page 40)

This will examine the emergence of deviations such that the deviation lifecycle model can be applied and a contingency plan devised to apply corrective action prior to it adversely impacting the task delivery performance (and by integration across the project network, impacting project performance).

The investigation has the objective of identifying issues that could reasonably be recognised 'before the event' to allow prediction of performance failures to be conducted and a contingency plan to be devised. As decided in chapter five, this will be achieved through a combination of case studies and CIT that examine the objectives of the research model and investigate its potential influence on project behaviour.

The industrial position of the research model needs to be considered. The research model was developed in recognition of the need for predictive tools and techniques. The Deviation Lifecycle – Industrial Model (DLC-IM) does not have any history of application in practice, so there is no pre-existing database or level of expertise that can be explored to obtain relevant data. Whilst the case studies offer an illustration of potential industrial application, it is unlikely (near impossible) that commercial organisations would devote the resources to conduct a new process without evidence of its potential benefit, Consequently, the investigation of the DLC – IM must be considered to be representations of the way in which the process could be applied. Any actual application might identify different success / failure topics and issues within the FMEA, and consequently apply different mitigation within the WS-TP analysis.

The first case study utilises an existing case study (Coley 2008) to provide a documented baseline to examine development of the research model by investigating application of the initial pathogens model and its development to the DLC-IM. Having examined the relationship between pathogens and the DLC-IM and established a baseline in the first case, subsequent cases focus on the DLC-IM. The second case study focuses on the DLC-IM and tests its application to a single task. This is developed in the third case study to examine how the model might be applied in an industrially based multi-task case. The fourth and fifth cases examine two stages in an active research project to demonstrate practical application of the research model.

In all of the case studies, except the single task focus in the second, multiple topics within the project being examined were investigated. The analysis of success criteria in chapter six identified seventeen topics to be tested. Where each criterion was applied, in many cases multiple examples of potential failures were identified. This resulted in a significant volume of individual applications of the research model. The role of the initial FMEA is to filter the number of topics to which WS-TP analysis is applied. Table ten summarises the initial work that was conducted, and identifies the initial number of lines to which the analysis was applied and the filtering effect of the FMEA to identify the topics with RPN ≥ 100.

Table 10: Summary of initial DLC-IM analysis

Case	Theme / Topic	Number of lines	RPN's ≥ 100
Coley	10	261	119
Kitchens	1	48	18
Facility development	7	571	244
Research	7	758	265
Research	8	613	207
Total	33	2251	853

The presentation of the case studies is a summary of the initial work carried out. In this chapter the case studies are presented with individual examples of the application of the research model. Additional tables are given in the appendices, limited to no more than a ten item summary of the FMEA table and WS-TP table, except for Appendix B that provides an example of the full analysis of the single task analysed in the second case study.

5.1 Case study (1): LIFECar

"The Lightweight Integrated Fuel Efficient Car (LIFECar) Project was initiated as a venture to design and manufacture a zero emission sustainable sports car"[5] (Coley, 2008, page 74). "*Whole system design*" is investigated by Coley (2008), prompted by the "*demand for more environmentally sustainable design across a multitude of contexts"* (Coley, 2008, page 1). Coley's research was "*concerned with looking at the design process from a whole system perspective*" (Coley, 2008, pg. 3) and identifies 10 themes within the "*LIFECar*" case study. In this analysis, each 'theme' is treated as a task. This allows data to be gathered to support the use of CIT (Flanagan 1954) to analyse the detail. Subsequent case studies conducted by Coley (2008) are not reviewed in this assessment. The intention of this case study was to conduct a retrospective analysis to allow the foundation of the research model to be tested against public domain documentation.

The opportunity is to examine the initial 'pathogens' research model developed from the literature (DLC-LM, figure 20) and the development of the theoretical model (DLC-TM, figure 23). The test is to examine whether this can be achieved by applying the DLC-IM (figure 24). Within each theme the CIT (Flanagan, 1954) stage of collecting data was applied and a range of topics were identified, and an example is presented in each of the theme discussions.

The success / failure criteria are examined to identify examples of 'potential effects of failure', their relation to 'pathogens', and to test the relevance of the theme to project performance. This also provides initial analysis as required by

[5] Further information at: http://www.riversimple.com

the CIT (Flanagan, 1954). Further analysis is given at the end of the case study and in chapter eight.

This allows subsequent case studies to develop and test different aspects of the process.

It must be stressed that the discussion presented here is an interpretation of the data presented in Coley (2008) that has the objective of examining the potential application of the research model. The analysis presented here does not directly correlate to the performance of the LIFECar project and is not intended to restructure or revise Coley (2008).

5.1.1 Summary of case study

Theme one: Group Composition

The purpose of "Group Composition" is described by Coley (2008, pg. 96): *"one of the key principles of successfully undertaking a whole system design is the integration of multiple perspectives combined with complementary expertise, experience, ability and competence".*

Applying the data collection stage of CIT (Flanagan, 1954) initial topics can be identified and assessed by the DLC-IM using FMEA, and considering the pathogen and incubation process, followed by WS-TP analysis.

FMEA and pathogen-incubation

The initial FMEA and related pathogen-incubation process identified 39 topics of which 15 topics showed RPN ≥ 100. Summary analysis is presented in tables 77 (appendix B.1.1). The example (table 11) examines the issue of sub-contractors not committing to the project and aligns with the organisation pathogen and habituation incubation process.

Table 11: Theme One: FMEA and pathogen-incubation example

Process Step	Potential Failure Modes	Potential Effects of Failure	Pathogen Incubation	SEV	Potential Cause(s) / Mechanism(s) of Failure	OCC	Current Process Controls	DET	RPN
Group Composition									
	Time	Schedule delays to project	Organisation Habituation	7	Subcontractors will select personnel according to their own process	5	Consider specific constraints on sub-contractors – include as risk?	7	245

WS-TP

The filtering process of identifying topics with RPN ≥ 100 defines the sub-set to which WS-TP analysis can be applied. In this theme, fifteen items were identified as requiring further analysis (table 78 in Appendix B.1.2).

For each of the topics in the sub-set, identification of WS and definition of criteria to identify how the TP might emerge can be established. Table 12 presents WS and TP analysis applied to the example given in table 11.

Table 12: Theme One: WS-TP analysis

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	RPN	Weak Signals	Tipping Point
Group Composition						
	Time	Schedule delays to project	Subcontractors will select personnel according to their own process	245	Sub-contractor specialist unavailable to attend review meeting. Sub-contractors do not provide clear evidence of actions to support schedule	Sub-contractor specialist does not attend multiple review meetings. Sub-contractors do not provide clear evidence of actions to support schedule at subsequent review

Analysis

Coley (2008) examines group composition in order to test integration. Applying the analysis stage of CIT (Flanagan, 1954) a project performance perspective suggests issues with different actors adversely impacting on the integration activities. Early recognition of subcontractors focusing their attentions elsewhere has potential to reduce adverse impact. The DLC-IM process raises awareness of this possibility, allowing mitigation plan to be considered.

In table 11, it might be considered that the subcontractors selecting personnel to their own process resulting in an RPN of 245 requires immediate corrective action. This is, of course, an acceptable course of action if the judgement is that the impact would be unacceptable. Otherwise, applying the WS-TP analysis will allow the emergence of the topics to be identified and criteria by which corrective action should be applied to be defined prior to the emergence of a task deviation that would impact the project performance, as per table 12. It might be that the case that the subcontractor recognises that the prime contractor has identified the potential problem and takes action to ensure that the focus is maintained.

Theme two: Communication

The purpose of “Communication” is described by Coley (2008, pg. 106): *“For any collaborative project to be successful, effective communication is essential”.* Communication is a topic for which activities within the project can be developed to counter predicted issues; part of the role of communications is to keep consistent information distribution across the project. Applying the data collection stage of CIT (Flanagan, 1954) initial topics can be identified and assessed by the DLC-IM using FMEA, and considering the pathogen and incubation process, followed by WS-TP analysis.

Failure Modes and Effects Analysis and pathogen-incubation

The initial FMEA and related pathogen-incubation process identified 30 topics of which 16 topics showed RPN ≥ 100, summarised in table 79 (appendix B.2.1).

The example (table 13) examines the issue of communication within the project and aligns with the practice pathogen and complexity incubation process.

Table 13: Theme Two: FMEA and pathogen-incubation example

Process Step	Potential Failure Modes	Potential Effects of Failure	Pathogens Incubation	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Communication									
	Communications	*"This potentially prevented an understanding of how components of the design impacted upon each other. Additionally opportunities for optimisation between components of the design could have been overlooked and this put the realisation of a fully integrated design at risk"* (Coley 2008)	Practice Complexity	6	*Outside of team-meetings, team-members often neglected to communicate frequently and consistently with the whole team.* (Coley 2008)	5	Need to maintain communication between team members	4	120

WS-TP

WS-TP analysis is summarised in table 80 (appendix B.2.2). The example is continued in table 14.

Table 14: Theme Two: WS-TP analysis

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Communication							
	Communications	*"This potentially prevented an understanding of how components of the design impacted upon each other. Additionally opportunities for optimisation between components of the design could have been overlooked and this put the realisation of a fully integrated design at risk"* (Coley 2008)	*Outside of team-meetings, team-members often neglected to communicate frequently and consistently with the whole team.* (Coley 2008)	Need to maintain communicat ion between team members	120	Team or review meetings identify communication activities that should have been completed between meetings	Team or review has to be re-scheduled to allow work to be completed or revised

Analysis

Coley (2008) identified the problem of communication. The analysis stage of CIT (Flanagan, 1954) recognises that communication is good practice and necessary in complex projects. The example illustrates broad recognition of this. Control and distribution of information in projects to ensure work is based on latest data is critical.

This example highlights the problem across team members. Maintaining communications and developing focus on team reviews can be resolved. It is also an opportunity to examine a stakeholder’s attitude to project progress.

Theme three: Individual Characteristics

The purpose of “Individual Characteristics” is described by Coley (2008, pg. 116): *“Successful whole system design requires the integration of multiple perspectives combined with complimentary expertise, experience, ability and competence. Subsequently the mix of people within a project team can have a substantial effect on the success of the project as a whole. The individual characteristics of those people, however, have been observed to be equally as important”.*

This topic focuses on how individuals respond to project process, in this case change process. This can have a negative impact on individuals if project changes prompt rework. Applying the data collection stage of CIT (Flanagan, 1954) initial topics can be identified and assessed by the DLC-IM using FMEA, and considering the pathogen and incubation process, followed by WS-TP analysis.

FMEA and pathogen-incubation

The initial FMEA and related pathogen-incubation process identified 23 topics of which nine topics showed RPN ≥ 100. The analysis presented table 81 (Appendix B.3.1) presents a summary of the application of the DLC-IM. The example (table 15) examines the issue of project change and its impact on individual characteristics and aligns with the practice pathogen and habituation incubation process.

Table 15: Theme Three: FMEA and pathogen-incubation example

Process Step	Potential Failure Modes	Potential Effects of Failure	Pathogen Incubation	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Individual characteristics									
	Project Change	Ability to recognise impact of change	Practice Habituation	6	Individual focus on activities ignores bigger picture.	5	Individual awareness of change control process	5	150

WS-TP

WS-TP analysis is given in table 82 (appendix B.3.2). The example is continued in table 16.

Table 16: Theme Three: WS-TP analysis

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Individual characteristics							
	Project Change	Ability to recognise impact of change	Individual focus on activities ignores bigger picture.	Individual awareness of change control process	150	Change control requires re-work	Component designs are scrapped and new designs required.

Analysis

Impact of change is potentially the most challenging to individual characteristics. Managing the change process is a 'practice' of which organisations attempt to apply 'best practice'. The change process and impediments to its efficient application stem from habit. The DLC-IM offers opportunity to define a mitigation plan to minimise adverse effects. This illustrates the need for early action to minimise adverse change control issues and how individuals respond to changes. CIT (Flanagan, 1954) analysis identifies that the predictive role of this topic could highlight an issue that influences staff selection. If this is conducted incorrectly (selecting a staff member with the wrong individual characteristics) it could have an adverse impact on project performance.

Theme four: Commitment

The purpose of "Commitment" is described by Coley (2008, pg. 119): *"A characteristic which has been observed to be a pertinent requirement of those working on a whole system design is commitment to both the project and to the project team".*

This is another topic where the overall organisation and how stakeholders develop and interact with the project organisation can influence project performance. Applying the data collection stage of CIT (Flanagan, 1954) initial topics can be identified and assessed by the DLC-IM using FMEA, and considering the pathogen and incubation process, followed by WS-TP analysis.

FMEA and pathogen-incubation

The initial FMEA and related pathogen-incubation process identified 22 topics of which five topics showed RPN ≥ 100. The analysis presented in table 83 (Appendix B.4.1) examines the application of the DLC-IM. The example (table 17) examines the stakeholder role in commitment to the project and aligns with the organisation pathogen and reinforcement incubation process.

Table 17: Theme Four: FMEA pathogen-incubation example

Process Step	Potential Failure Modes	Potential Effects of Failure	Pathogens Incubation	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Commitment									
	Stakeholders	*"This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required"* (Coley 2008)	Organisation Reinforcement	6	*"It was apparent that some partners were not aware of the level of commitment that was required of them."* (Coley 2008)	6	Top management commitment to support project	5	180

WS-TP

WS-TP analysis is given in table 84 (appendix B.4.2). The example is continued in table 18.

Table 18: Theme Four: WS-TP analysis

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Commitment							
	Stakeholders	*"This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required"* (Coley 2008)	*"It was apparent that some partners were not aware of the level of commitment that was required of them."* (Coley 2008)	Top management commitment to support project	180	Multiple attempts are required to ensure stakeholders maintain commitment	Lack of Stakeholder commitment leads to delays in delivering tasks

Analysis

Applying the analysis stage of CIT (Flanagan, 1954), Commitment is often a reflection of the organisations attitude and is reinforced by stakeholders attitudes. Detecting loss of commitment is critical to maintaining progress of a project. Top management have the most significant impact on the 'attitude' and 'culture' of the project organisation. This highlights the need for early action with, and inclusion of, stakeholders to maintain commitment.

Theme five: Motivation

The requirement for "Motivation" is described by Coley (2008, pg. 124): *"It was observed that high levels of commitment from actors were often unobtainable without significant motivation towards the project".* Applying the data collection stage of CIT (Flanagan, 1954) initial topics can be identified and assessed by the DLC-IM using FMEA, and considering the pathogen and incubation process, followed by WS-TP analysis.

FMEA and pathogen-incubation

The initial FMEA and related pathogen-incubation process identified 21 topics of which nine topics showed RPN ≥ 100. The analysis presented table 85 (Appendix B.5.1) examines the application of the DLC-IM. The example (table 19) examines motivation to achieve quality within the project and aligns with the organisation pathogen and complexity incubation process.

Table 19: Theme Five: FMEA and pathogen-incubation example

Process Step	Potential Failure Modes	Potential Effects of Failure	Pathogens Incubation	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Motivation									
	Quality	Product does not meet customers requirements	Organisation Complexity	8	*"Due to conflicting goals, compromises within the design had to be agreed upon by partners. This meant that not all individual goals could be achieved. This, however, led to compromises being made between partners. This was essential for the successful development of a final solution."* (Coley 2008)	5	Analysis against project requirements	3	120

WS-TP

WS-TP analysis is summarised in table 86 (appendix B.5.2). The example is continued in table 20.

Table 20: Theme Five: WS-TP analysis

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Motivation							
	Quality	Product does not meet customers requirements	*"Due to conflicting goals, compromises within the design had to be agreed upon by partners. This meant that not all individual goals could be achieved. This, however, led to compromises being made between partners. This was essential for the successful development of a final solution."* (Coley 2008)	Analysis against project requirements	120	Evidence of goal conflict between different stakeholders	Stakeholder focuses on individual rather than project goal

Analysis

The organisation and its management of complexity will have a significant impact on motivation. CIT (Flanagan, 1954). Analysis suggests that bad organisation and unnecessary complexity will demotivate. These issues need to be identified and resolved early. The potential is ongoing incubation before problems emerge.

Theme six: Identity

The purpose of "Identity" is described by Coley (2008, pg. 129): *"…it is important for actors to integrate with each other, the first step of which is* *identifying with both the purpose of the project and the other people working on that project".* Applying the data collection stage of CIT (Flanagan, 1954) initial topics can be identified and assessed by the DLC-IM using FMEA, and considering the pathogen and incubation process, followed by WS-TP analysis.

FMEA and pathogen-incubation

The initial FMEA and related pathogen-incubation process identified 20 topics of which seven topics showed RPN ≥ 100. The analysis presented table 87 (Appendix B.6.1) examines the application of the DLC-IM. The example (table 21) examines the issue of scope creep as a consequence of actors understanding of the purpose of the project, leading to them developing enhancements as they identify more closely with the detail and team. This aligns with the organisation pathogen and habituation incubation process.

Table 21: Theme Six: FMEA and pathogen-incubation example

Process Step	Potential Failure Modes	Potential Effects of Failure	Pathogens Incubation	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
identity									
	Scope	Scope creep or schedule / cost increase	Organisation Habituation	5	Contractors other interests override scope due to not identifying with the project	6	None	10	300

Scope creep is a common problem, Identifying creep and minimising resource being wasted is an important topic for project managers. This application of the DLC-IM model identifies this issue. This can prompt specific action to avoid its occurrence and impact on schedule and resource cost. The high RPN value indicates early or immediate action might be beneficial.

WS-TP

WS-TP analysis is summarised in table 88 (appendix B.6.2). The example is continued in table 22.

Table 22: Theme Six: WS-TP analysis

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Identity							
	Scope	Scope creep or schedule / cost increase	Contractors other interests override scope due to not identifying with the project	None	300	Review of scope of specific task	Task scope impacts project network – causing restructuring of project

Analysis

CIT (Flanagan, 1954) analysis identifies that scope creep is a common issue but action to minimise is often limited. Identifying organisation pathogen and habituation incubation processes to apply early mitigation could help to reduce the adverse impact.

Theme seven: Sense Making

The purpose of "Sense Making" is described by Coley (2008, pg. 132): *"The integration of individual perspectives, ideas and knowledge is essential to developing a whole system perspective".*

Retaining 'sense' within the project is important to keep focus on tasks and their contribution to delivering the task and overall objectives at an acceptable level of performance. Applying the data collection stage of CIT (Flanagan, 1954) initial topics can be identified and assessed by the DLC-IM using FMEA and considering the pathogen and incubation process, followed by, WS-TP analysis.

FMEA and pathogen-incubation

The initial FMEA and related pathogen-incubation process identified 29 topics of which 18 topics showed RPN ≥ 100, summarised in table 89 and 90 (Appendix B.7.1). The example (table 23) examines the stakeholder role of communication in making sense in a complex project and aligns with the task pathogen and complexity incubation process.

Table 23: Theme Seven: FMEA and pathogen-incubation example

Process Step	Potential Failure Modes	Potential Effects of Failure	Pathogen Incubation	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Sense Making									
	Communications	Product design standard is defined in a multiple of ways and makes no sense causing confusion leading to rework and delay / cost increase -	Task Complexity	7	*"This was difficult as other partners were not able to fully comprehend what they were explaining"* (Coley 2008)	7	*"Partners communicated initially using their own terminology." (Coley 2008)*	4	196

WS-TP

WS-TP analysis is summarised in tables 91 and 92 (appendix B.7.2). The example is continued in table 24.

Table 24: Theme Seven: WS-TP analysis

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Sense Making							
	Communications	Product design standard is defined in a multiple of ways and makes no sense causing confusion leading to rework and delay / cost increase -	*"This was difficult as other partners were not able to fully comprehend what they were explaining"* (Coley 2008)	*"Partners communicated initially using their own terminology." (Coley 2008)*	196	Indication of misunderstanding of product design standards between stakeholders.	Communications have to be revised .

Analysis

Making sense and communicating is a significant challenge, particularly as the complexity of the project increases. CIT (Flanagan, 1954) analysis shows that there is a relation between the pathogens and incubation and adverse impact on task performance. Thus it is essential to ensure communications of product design to avoid any misunderstanding. Co-ordinating design understanding between partners is recognised. Investigating potential issues early in the task lifecycle offers an opportunity to reduce deviation and improve performance.

Theme eight: Managing Uncertainty

The concern of "Managing Uncertainty" is described by Coley (2008, pg. 143): *"Two of the most challenging aspects of developing a holistic and sustainable solution appear to be: firstly, as previously highlighted, making sense of the complexity that is bought to the design process by the multiple actors; and secondly, learning to manage the level of uncertainty".* Applying the data collection stage of CIT (Flanagan, 1954) initial topics can be identified and assessed by the DLC-IM using FMEA, and considering the pathogen and incubation process, followed by WS-TP analysis.

FMEA and pathogen-incubation

The initial FMEA and related pathogen-incubation process identified 24 topics of which 15 topics showed RPN ≥ 100, summarised in table 93 (appendix B.8.1). The example (table 25) examines the problem of managing, and bounding, the project scope in an uncertain environment. This aligns with the task pathogen and quantity incubation process.

Table 25: Theme Eight: FMEA and pathogen-incubation example

Process Step	Potential Failure Modes	Potential Effects of Failure	Pathogens Incubation	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Managing Uncertainty									
	Scope	Wrong scope delivered due to uncertainty	Task Quantity	7	Insufficient understanding of scope causes uncertainty	6	Scope definition as part of bid process – ensure clear definition of project boundaries	4	168

WS-TP

WS-TP analysis is summarised in table 94 (appendix B.8.2). The example is continued in table 26.

Table 26: Theme Eight: WS-TP analysis

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Managing Uncertainty							
	Scope	Wrong scope delivered due to uncertainty	Insufficient understanding of scope causes uncertainty	Scope definition as part of bid process – ensure clear definition of project boundaries	168	Scope uncertainty emerges	Task completion or design review identified scope error

Analysis

CIT (Flanagan, 1954) Analysis identifies that Uncertainty is central to the challenge of delivering projects. Understanding scope is a common problem. Taking action around these pathogen-incubation criteria will impact all aspects of the task, and by integration across the task network, the project.

Theme nine: Collaboration

The purpose of "Collaboration" is described by Coley (2008, page 147): *"collaboration is a key to any integrative design project".* Applying the data collection stage of CIT (Flanagan, 1954) initial topics can be identified and assessed by the DLC-IM using FMEA, and considering the pathogen and incubation process, followed by WS-TP analysis.

FMEA and pathogen-incubation

The initial FMEA and related pathogen-incubation process identified 29 topics of which 12 topics showed RPN ≥ 100, summarised in table 95 (appendix B.9.1). The example (table 27) examines the need for top management support in a collaborative environment and aligns with the convention pathogen and habituation incubation process.

Table 27: Theme Nine: FMEA and pathogen-incubation example

Process Step	Potential Failure Modes	Potential Effects of Failure	Pathogen Incubation	SEV	Potential Cause(s) / Mechanism(s) of Failure	OCC	Current Process Controls	DET	RPN
Collaboration									
	Top Management Support	Increased work or re-work leading to task / project delay / increased costs	Convention Habituation	6	Top management support and direction does not support collaboration in the context of detailed task activities	5	Top management review and understanding of project plan	4	120

WS-TP

WS-TP analysis is summarised in table 96 (appendix B.9.2). The example is continued in table 28.

Table 28: Theme Nine: WS-TP analysis

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Collaboration							
	Top Manage ment Support	Increased work or re-work leading to task / project delay / increased costs	Top management support and direction does not support collaboration in the context of detailed task activities	Top management review and understanding of project plan	120	Top Management Support is restricted on resolution of collaboration issues leading to increased work or re-work and task / project delay / increased costs	Lack of top management support leads to identifiable increased work or re-work and task / project delay / increased costs

Analysis

Collaboration is, by its nature, arranged in the early stages of the project. Analysing the potential for issues at an early stage is critical. CIT (Flanagan, 1954) analysis suggests establishing mitigation is necessary to manage collaboration activities.

Theme ten: Ownership

The purpose of "Ownership" is described by Coley (2008, pg. 154): "*Ownership can be separated into two parts; the physical ownership of belongings, work, ideas etc. and the psychological ownership which refers to the feeling of wanting to make a difference. It is suggested that the latter goes beyond duty and commitment in that members of the team begin to tie their identity to a* *projects outcome, thus injecting extra effort to ensure its success*". Applying the data collection stage of CIT (Flanagan, 1954) initial topics can be identified and assessed by the DLC-IM using FMEA, and considering the pathogen and incubation process, followed by WS-TP analysis.

FMEA and pathogen-incubation

The initial FMEA and related pathogen-incubation process identified 24 topics of which 13 topics showed RPN ≥ 100, summarised in table 97 (appendix B.10.1). The example (table 29) examines the need for the project team to take ownership of the project and aligns with the organisation pathogen and complexity incubation process.

Table 29: Theme Ten: FMEA and pathogen-incubation example

Process Step	Potential Failure Modes	Potential Effects of Failure	Pathogens Incubation	SEV	Potential Cause(s) / Mechanism(s) of Failure	OCC	Current Process Controls	DET	RPN
Ownership									
	Project Team	*"This led to un-motivated team members and a lack of progress"* (Coley 2008)	Organisation Complexity	5	*"Initially partners were reluctant to take ownership for the project. This was because the project was very ambitious and ambiguous and partners were not willing to 'jump in' when it could potentially all go wrong."* (Coley 2008)	6	Requirements definition, work share and project plan	5	150

WS-TP

WS-TP analysis is summarised in table 98 (appendix B.10.2). The example is continued in table 30.

Table 30: Theme Ten: WS-TP analysis

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Ownership							
	Project Team	*"This led to un-motivated team members and a lack of progress"* (Coley 2008)	*"Initially partners were reluctant to take ownership for the project. This was because the project was very ambitious and ambiguous and partners were not willing to 'jump in' when it could potentially all go wrong."* (Coley 2008)	Requirements definition, work share and project plan	150	Project Team members being reluctant to take ownership of tasks due to project ambition and ambiguity.	Early design review activities identifies clear lack of progress towards initial objectives or early stage design review, identified as being due to project team members not accepting ownership of tasks.

Analysis

CIT (Flanagan, 1954) analysis identifies ‘ownership’ or, more importantly, when actors lose ownership through organisation change or as the project culture changes. Recognising this is critical to enable a prompt response and reduction of adverse impact.

5.1.2 Case study (1): Discussion

The initial case study, based on Coley (2008) had the objective of examining the application of the initial literature and theoretical (DLC-TM) research model against a documented project. Coley’s thesis is available at the British Library ‘ETHOS’ website[6]. The second aspect of the analysis of Coley (2008) was to examine the initial theoretical model and the development of this towards an industrially applicable research model.

Across the ten themes, 261 initial topics were identified of which 119 showed RPN ≥ 100. This indicates that the initial task of applying FMEA to test performance issues can identify potential topics, and the RPN analysis can filter those that require additional attention. This allows focus on those topics with RPN ≥ 100 with respect to defining a mitigation plan and criteria by which it might be applied.

To achieve the second objective, the topics analysed have identified relevant pathogens as well as examining the criteria using the DLC-IM.

There is an alignment between the theoretical model (DLC-TM) and the industrial model (DLC-IM).

Applying CIT (Flanagan, 1954) analysis shows that WS criteria that relate to the performance of the task (in the context of Coley’s theme) can be identified and TP criteria show when the topic has become critical and necessary for corrective action to be taken.

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[6] http://ethos.bl.uk/Home.do

Reference to comments on pathogens and correlation to DLC-IM – suggests that this is reasonable and indicates pathogens model in chapter 5 was a reasonable starting point and provides a reasonable basis to proceed based on DLC-IM only. Analysis across the ten themes suggests DLC-IM can provide an assessment of potential performance issues. This will be further investigated in following case studies.

5.2 Case study (2): Single task analysis

The second case study builds on the first case study by taking a single task and focuses on application of the DLC-IM. Within a project to install a kitchen, a single task might be defined as the fitting of the oven and microwave. This is investigated to examine potential performance issues.

Developing the initial analysis to focus on a specific single task allows focus on the process model. The analysis of Coley (2008) showed that the proposed model has the potential to identify topics that could influence project performance, but was intentionally based on an existing documented project. Developing from Coley (2008) required a case study that removed the complexities of the project organisation or required understanding of a complex engineering process. Selection of a single task allows focus on the application of the research model.

Within the case study the CIT (Flanagan, 1954) stage of collecting data was applied and a range of topics were identified, examples are presented and discussed.

The success / failure criteria are examined to identify examples of ‘potential effects of failure’, and to test the relevance to project performance. This also provides initial analysis required by the CIT (Flanagan, 1954). Further analysis is given at the end of the case study and in chapter eight.

A schematic example is shown in Figure 25, and identifies the general arrangement required for both the supporting structures for the oven and microwave, as well as the cosmetic finishing required by the customer. Whilst the issues of heating and control of the oven are within the units design, there are specific constraints in installation to ensure safe supply of services (Gas, Electricity) and cooling, whilst it is also necessary to achieve a cosmetically acceptable installation for the customer. Figure 26 illustrates the level of installation information typically provided by the oven manufacturer, from which the installer has to achieve an acceptable installation. It is a common problem during the installation activity that technical details need to be resolved, otherwise customer expectations may not be achieved.

Investigating this particular example, and considering how the FMEA technique might be developed to improve the delivery process has potential to offer benefits to the supply chain as well as improving customer satisfaction. As this case only examines one topic, the full FMEA table is presented.

Application of the DLC-IM can investigate the installation process and test for potential performance issues. Examples of the FMEA table are shown at table 32 and 33.

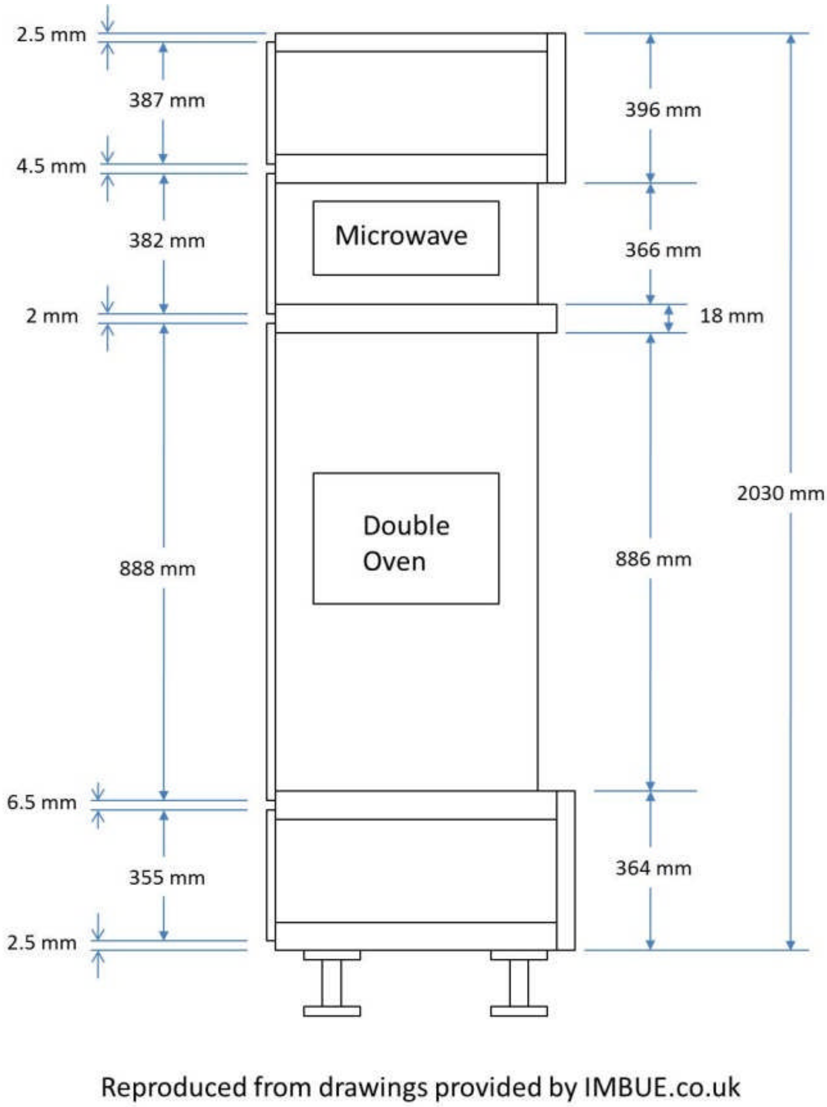

Figure 25: Cabinet geometry

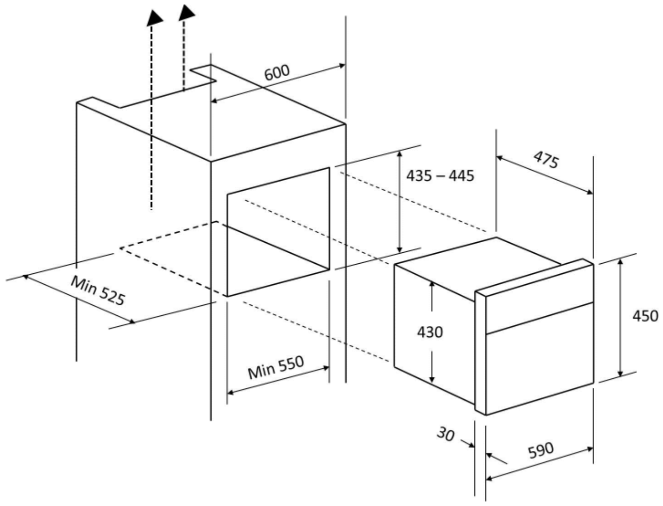

Figure 26: Oven geometry

5.2.1 Summary of case study

This case study focused on a single task to examine the potential application of the research model in the smallest element of the project network, the single task, as developed within the earlier discussion as the research focus.

This provides a foundation to which the research model can be applied to more complex situations, and examines the application to the single task within the context of larger projects, and how this changes at different stages of the project lifecycle.

This allowed eighteen topics to be identified that could adversely impact the delivery performance of the oven installation, with potential consequences of impacting the overall project performance.

This provides a foundation from which the application of the research model can be tested

The overall FMEA identified 48 topics and 18 cases where RPN ≥ 100.

FMEA topics with RPN ≥ 100 were found in the success criteria:

- Project control / Process
- Stakeholders
- Contracts
- Project Change
- Project Team
- Technology
- Time (x3)

This indicates that there is potential for deviation across the task. The FMEA identifies the key topics that have potential to impact performance.

For each case where the FMEA identifies a topic with RPN ≥ 100, it is then possible to identify the WS that constitute the early stages of a task deviation.

The specific criteria to identify WS focused on aspects of the task within the manager’s ability to observe, such as identifying a project control process and recognising this by evidence of prior tasks being tracked such that overall progress is known and subsequent tasks can be planned in detail. However, this cannot be applied throughout this type of project, as the potential for a customer to change a requirement remains present. This is an example of a deviation that can only be reacted to, although there is still the opportunity to pre-plan the mitigation, for example, by having a customer review at which they commit to the design and accept costs and delays, should they change their mind.

For these topics, identification of TP; Project control / Process, Stakeholders, Contracts, Project Change, Stakeholders, Project Team, Technology, Time (x3).

For each of the WS, it is possible to define the criteria that indicate a TP has been reached and then the corrective actions to be taken. This allows the development of deviations to be monitored to ensure their impact on the progress of the task (and by integration across the project network, the delivery performance of the complete project) is minimised. This also allows corrective action to be applied at the most cost effective point.

Example of stakeholders changing requirements (RPN = 168) is a typical problem. Whilst it is difficult to predict what feature of the requirements and which stakeholder might prompt the change, but recognising the potential allows a response strategy to be considered.

5.2.2 Case study (2): Discussion

This case study provided a broader analysis focused on a single task to reflect the research focus developed in chapter three and four, and concentrates on application of the research model.

Applying CIT (Flanagan, 1954) analysis, there was the opportunity to identify a range of issues and determine the WS-TP, leading to mitigation plans. Overall this supports the potential to apply the research model.

Table 31: Single task: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Oven installation								
	Project Control / Process	Project schedule delays – cost increase due to additional work to resolve – need to introduce new or additional project control Knock on effect to other projects	8	Lack of project control process or no control process	4	Overall process not known or understood	6	192
	Stakeholders	Customer changes requirement	7	Customer community influenced by external events	8	Contract agreement review with customer	3	168

Table 32: Single task: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Oven installation							
	Project Control / Process	Project schedule delays – cost increase due to additional work to resolve – need to introduce new or additional project control Knock on effect to other projects	Lack of project control process or no control process	Overall process not known or understood	192	Project Control not apparent/ Process for oven installation not clear – contractor requires instruction, or additional information has to be obtained from the manufacturer	Project Control cannot track progress / Process for oven installation cannot proceed because required information is not available – OEM has not provided sufficient information or support
	Stakeholders	Customer changes requirement	Customer community influenced by external events	Contract agreement review with customer	168	Stakeholders changes requirement for oven installation	Stakeholders change of requirements impacts oven installation, causing delays that impact progress of kitchen installation which requires rescheduling of subsequent project.

5.3 Case study (3): Facility development

Many industrial projects have the objective of developing facilities for manufacturing or service functions. The third case study develops the application of the research model (DLC-IM) by examining a generic industrial project developing manufacturing facilities such as multiple machining centres and injection moulding facilities. For example, Fan (1988). This case study builds on the previous studies by developing the application of the DLC-IM analysis into a project more typical of the industrial environment.

Within the case study the CIT (Flanagan, 1954) stage of collecting data was applied and a range of topics were identified, and an example is presented and discussed.

The success / failure criteria are examined to identify examples of ‘potential effects of failure’, and to test the relevance to project performance. This also provides initial analysis as required by the CIT (Flanagan, 1954). Further analysis is given at the end of the case study and in chapter eight.

5.3.1 Summary of case study

A generic case study was devised to represent an activity that occurs across multiple industrial sectors. In order to achieve an industrial capability a facility must be developed with the capability and capacity to deliver the industrial activity. In many cases this requires the installation of manufacturing equipment as discussed in the case study.

This case study took a project with multiple tasks and examined several of the key tasks. Initial analysis identified seven topics and generated 571 applications of the research model, with 244 examples of RPN $\geq$ 100. These are examined in this section, with summary tables in appendix D.

Topic 1: Customer requirements

The objective of this task is to 'decompose' complete and demonstrate compliance to defined customer requirements. The initial challenge is recognising requirements, particularly for stakeholders working for prime contractors or in customer's facilities. The objective of the activity is matching organisation and stakeholders' capabilities of delivering customer requirements. The challenge of getting the organisation correct to deliver the task is critical; it is an easy topic to identify as relevant to performance.

Setting up the initial organisation to undertake work required to deliver requirements is a challenge in the early stages of a project, when uncertainty and risk of change is at its highest. Getting this organisation right at the detail task level, so that issues can be identified and appropriate response is applied, is fundamental. Developing the organisation to adapt to changing requirements is also critical. The mitigation plans must reflect this.

FMEA

The initial FMEA identified 34 topics with 12 showing RPN ≥ 100. The analysis presented in table 105 (appendix D.1.1). The example (table 33) examines stakeholders response to customer requirements.

Table 33: Customer requirements: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Customer requirements								
	Stakeholders	Customer stakeholders incorrectly identified.	7	Failure to understand how the organisation of stakeholders will function	6	Project plan and stakeholder management	4	168

This example examines how stakeholder's interests align to customer requirements. The examination tests if it is in the stakeholder's interest to deliver customer requirements. Analysis considers how this contributes positively to project performance.

WS-TP

WS-TP analysis is summarised in table 106 (appendix D.1.2). The example is continued in table 34.

Table 34: Customer requirements: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Customer requirements							
	Stakeholders	Customer stakeholders incorrectly identified.	Failure to understand how the organisation of stakeholders will function	Project plan and stakeholder management	168	Stakeholders query or don't respond to planned or agreed activities. Action is required to prompt stakeholders to progress or deliver planned actions.	Expected deliveries don't occur to planed criteria.

What strategy is to be applied to resolve customer requirement issues with stakeholders?

TP mitigation allows stakeholders to be tested at an early stage to ensure performance and prompts early action on a topic that is likely to get worse.

CIT analysis (Flanagan, 1954) suggests that impact of deviations is likely to be significant, and the knock on effects to completion of the project, subsequent projects as well as correction of the error of misinterpreting customer requirements.

Topic 2: Fixture design and manufacture

Design and manufacture of fixtures and hardware is a long lead activity critical to the process being developed. Key requirement for a facility is the design and manufacture of bespoke fixtures and tooling required to establish the production process.

Issues with fixtures and tooling can lead to failure to deliver the required product. Detailed issues need to be resolved in the early stages when changes are more likely.

Understanding detailed requirements of customer, materials and supply chain as well as integration to the detailed design development, including topics such as CNC programming (see topic 3). Typically, fixtures will be manufactured by sub-contract specialists. Issues such as ensuring the design will do the job and delivering to schedule is critical. Ensuring that product details are finalised in time to allow fixture design and manufacture to be completed underlies the whole process.

Applying the data collection stage of CIT (Flanagan, 1954) and the DLC-IM initial topics can be identified and assessed by FMEA and WS-TP analysis.

FMEA

The initial FMEA identified 79 topics with 33 showing RPN ≥ 100. The analysis presented in table 107 (appendix D.2.1). The example (table 35) examines the impact of change.

It is often a concern that the schedule to design and manufacture fixtures is underestimated and additional time to complete has an adverse impact on tasks and the overall project.

Establishing a process to manage change can be identified predictively – therefore its mitigation can be assessed.

Table 35: Fixture design and manufacture: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Fixture design and manufacture								
	Project Change	Delivered product does not meet requirements	8	Group members avoid raising change requirements	5	Management review	5	200

Managing the impact of change on the detail design of the fixtures, and ensuring no changes impact manufacturing.

WS-TP

WS-TP analysis is summarised in table 108 (appendix D.2.2). The example is continued in table 36. Design review strategy is identified as the basis of managing the problem, but action between reviews is also important.

Table 36: Fixture design and manufacture: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Fixture design and manufacture							
	Project Change	Delivered product does not meet requirements	Group members avoid raising change requirements	Management review	200	Design review identifies issues that do not meet requirements	It becomes clear that need for changes in requirements were recognised but not acted on.

CIT analysis (Flanagan, 1954) identified timescales and implications for issues around design and manufacture of fixtures – for example, longer time taken to design and manufacture or functionality.

Topic 3 CNC programming

Time needed to produce accurate CNC programmes can be seriously underestimated. Programming has the same schedule issues as fixture design, and links to various stages of the manufacturing process. It is dependent on confirmation of design details and minimal change. Top management support is critical but may have unrealistic expectations.

Applying the data collection stage of CIT (Flanagan, 1954) and the DLC-IM initial topics can be identified and assessed by FMEA and WS-TP analysis.

FMEA

The initial FMEA identified 72 topics, with 34 showing RPN ≥ 100. The analysis presented in table 109 (appendices D.3.1). The example (table 37) examines the need for top management support to reinforce avoidance of change.

Table 37: CNC programming: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
CNC Programming								
	Top Management Support	Sub-contractor management don't prioritise project tasks leading to delay or project failure	8	Lack of priority from top management for specific CNC programming activity	5	Not communicated by top management	5	200

WS-TP

WS-TP analysis is summarised in table 110 (appendix C.3.2). The example is continued in table 38.

Table 38: CNC programming: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
CNC Programming							
	Top Management Support	Sub- contractor management don't prioritise project tasks leading to delay or project failure	Lack of priority from top management for specific CNC programming activity	Not communicated by top management	200	Scope to deliver code is ill defined	Schedule revision whilst corrective action is taken

CIT analysis (Flanagan, 1954) identifies problems if top management have unrealistic expectations which impacts schedule and costs.

Topic 4: Materials logistics: lifting and handling

Identifying and solving specific problems within a project is a significant challenge. Firstly, to isolate and bound the issue and secondly to scope the requirement to achieve a solution.

The example examines the requirement for specialised facilities for materials lifting and handling e.g. how to lift fixtures and billets in various stages of manufacture (and hence different masses and centre of gravity position change) whilst retaining the precision of alignment to allow them to be lifted on and off the machine and handled safely.

Problem of handling materials in the manufacturing facility, particularly as detail components are larger and therefore made from larger billets.

The underlying problem is the development of a bespoke solution to a requirement that is critical to the manufacturing process.

Applying the data collection stage of CIT (Flanagan, 1954) and the DLC-IM initial topics can be identified and assessed by FMEA and WS-TP analysis.

FMEA

The initial FMEA identified 92 topics of which 42 topics showed RPN ≥ 100. The analysis is presented in table 111 (appendices D.4.1). The example (table 39) examines the schedule issue of providing a bespoke solution, requiring the solving a complex and changing problem when detailed information is limited.

This requires specific understanding of the requirements of fixtures and materials. The risk is that the solution suppliers attempt to apply generic solutions to specific problems.

Table 39: Materials logistics: lifting and handling: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Task 5 – Materials logistics – lifting and handling								
	Time	Failure to provision lifting and handling facilities within task schedule impacts overall project delivery	8	Sub-contractor is not contracted to meet task or project schedule	6	Contract	4	192

WS-TP

WS-TP analysis is summarised in table 112 (appendix D.4.2). The example is continued in table 40.

Table 40: Materials logistics: lifting and handling: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Task 5 – Materials logistics – lifting and handling							
	Time	Failure to provision lifting and handling facilities within task schedule impacts overall project delivery	Sub-contractor is not contracted to meet task or project schedule	Contract	192	Mandated sub-contractor cannot offer a solution to meet task requirements	Alternative sub-contractor cannot offer a solution to meet task requirements

Need to identify a suitable sub-contractor with specialist understanding of the problem – and detailed progress review to develop a practical solution.

CIT analysis (Flanagan, 1954) identifies that project tasks have potential to be critical to the whole project and could impact deliveries to the customers.

Topic 5: Materials logistics: Supply chain

Supply chains are a major feature of manufacturing facilities, covering issues such as: raw material supply, initial preparation, e.g. forging billets, ensuring conformance to fit fixtures and CNC programming. Ensuring the logistics required to deliver products to customers is a key topic in the establishment of a manufacturing facility. Communication across the elements of the supply chain is needed to ensure the process is established and optimised.

Applying the data collection stage of CIT (Flanagan, 1954) and the DLC-IM initial topics can be identified and assessed by FMEA and WS-TP analysis.

FMEA

The initial FMEA identified 96 topics of which 40 topics showed RPN ≥ 100. The analysis presented in tables 113 (appendices D.5.1). The example (table 41) examines

Table 41: Materials logistics: supply chain: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Materials Logistics – Supply Chain								
	Communications	All issues around the project are likely to have an aspect of communications	7	Failure to communicate between actors	5	Regular communications meetings	5	175

Communication across the supply chain

WS-TP

WS-TP analysis is summarised in table 114 (appendix D.5.2). The example is continued in table 42. Lack of involvement of members of the supply chain identifies underlying issues that emerge as major challenges to the project.

Table 42: Materials logistics: Supply chain: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Materials Logistics – Supply Chain							
	Communications	All issues around the project are likely to have an aspect of communications	Failure to communicate between actors	Regular communications meetings	175	Supply chain not involved in communications – or do not attend reviews when invited	Communication failure leads to incorrect delivery from supply chain

CIT analysis (Flanagan, 1954) recognises the need for communications and challenges the prime contractor to maintain levels of communication required to ensure performance is achieved.

Topic 6: Manufacturing Process Documentation

Activities to ensure that the manufacturing process is fully defined and developed to deliver the product and meet quality requirements – resource / schedule to complete process.

- Level of process to be defined
- Need for documentation to communicate process and ensure conformance
- Understanding and application of legislation
- Risk of change

Applying the data collection stage of CIT (Flanagan, 1954) and the DLC-IM initial topics can be identified and assessed by FMEA and WS-TP analysis.

FMEA

The initial FMEA identified 97 topics of which 42 topics showed RPN ≥ 100. The analysis presented in table 115 (appendices D.6.1). The example (table 43) examines the process of meeting quality standards.

Table 43: Manufacturing Process Documentation: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Manufacturing Support Documentation								
	Quality	Failure to deliver to legislative requirements	8	Failure to recognise applicable legislation	6	Knowledge of legislation and relevant experience Formal review of legislation embodied in requirements	5	240

WS-TP

WS-TP analysis is summarised in table 116 (appendix D.6.2). The example is continued in table 44.

Table 44: Manufacturing Process Documentation: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Manufacturing Support Documentation							
	Quality	Failure to deliver to legislative requirements	Failure to recognise applicable legislation	Knowledge of legislation and relevant experience Formal review of legislation embodied in requirements	240	Need to review legislation	Need to revise design solution to meet legislation – documentation needs to be revised / reissued

CIT analysis (Flanagan, 1954) identifies the need to ensure correlation of the design solution and the need for process documentation to reflect legislation.

Topic 7: Short Term Production Delivery

Initial production activities are required to validate overall process. Issues that influence the potential to establish initial production and troubleshoot in the process of achieving routine ongoing production are investigated in this topic. Applying the data collection stage of CIT (Flanagan, 1954) and the DLC-IM initial topics can be identified and assessed by FMEA and WS-TP analysis.

FMEA

The initial FMEA identified 101 topics of which 41 topics showed RPN ≥ 100. The analysis presented in table 117 (appendices D.7.1). The example (table 45) examines the management of stakeholders within the short term production activity.

Table 45: Short Term Production Delivery: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Short Term Production Delivery								
	Stakeholders	*"This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required"* (Coley 2008)	6	*"It was apparent that some partners were not aware of the level of commitment that was required of them."* (Coley 2008)	6	Top management commitment to support project	5	180

WS-TP

WS-TP analysis is summarised in table 118 (appendix D.7.2). The example is continued in table 46.

Table 46: Short Term Production Delivery: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Short Term Production Delivery							
	Stakeholders	*"This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required"* (Coley 2008)	*"It was apparent that some partners were not aware of the level of commitment that was required of them."* (Coley 2008)	Top management commitment to support project	180	Impacts progress of activities required to support initial production	Need to rework materials to achieve initial production

Initial production integrates and validates the development activities and demonstrates the production process. CIT analysis (Flanagan, 1954) identifies issues that adversely affect the complete process and recognises the need for all actors to focus on the projects objectives and deliverables.

5.3.2 Case study (3): Discussion

This case study was devised as a generic example. It represents typical capability development projects conducted in numerous industries, in general, the design and installation of facilities to provide a manufacturing or service function. This requires a clear understanding of customer requirements, both external and internal to the industry, with the probability of change throughout the activities.

Designing manufacturing fixtures and associated CNC programming focuses on manufacturing facilities but both topics require stable information early in the process with significant adverse consequences of design change.

The problem of lifting and handling occurs in many industries. Components are increasing in size and integrated manufacturing process mean mass and detail complexity increases. This presents a challenge, integrally machined components in aerospace, larger more complex injection mouldings using larger tooling.

The remaining topics examined some of the issues required to establish initial production as part of the maturity process of delivering a manufacturing capability. All of these topics are subject to numerous influences that can impact performance.

This case study develops the application of the research model to examine the type of industrial development project in various applications. This provides a basis to focus the investigation on more active tasks.

5.4 Case study (4): Research project (part 1), Demonstration

Research projects cover a wide scope, for example Winter and Szczepanek (2009, pages 231-242). The fourth and fifth cases are based on an industrial research project (anonymised for the purposes of presentation) aimed at delivering process development to the manufacturing environment. They examine two stages of the Technology Readiness Level (TRL) maturity process (Mankins 1995). This extends the analysis to delivering performance across multiple stages of a project.

5.4.1 Summary of case study

This case study is based on an industrial research project delivering Technology Readiness Level (TRL) 5 (Mankins, 1995) to the customer. This project focused on the development and introduction of manufacturing processes to replace older processes and offer business benefits to the product manufacturer.

Within the case study the CIT (Flanagan, 1954) stage of collecting data was applied and a range of topics were identified. For each topic an example is presented and discussed.

The success / failure criteria are examined to identify examples of 'potential effects of failure', and to test the relevance to project performance. This also provides initial analysis as required by the CIT (Flanagan, 1954). Further analysis is given at the end of the case study and in chapter eight.

Topic 1: Repeatability

Basic process repeatability is critical and demonstrating the initial output of the research activity is important as the foundation of research at the higher TRL's. Repeatability builds on earlier TRL's that demonstrated basic process – showing that repeatability is critical to developing the underlying process integrity, for example, as the basis of a manufacturing process.

For a research process that is intending to demonstrate TRL 5, the basic process will have been achieved at TRL 4. This is a stepping stone to full process validation demonstration at TRL 6 prior to production embodiment at TRL 7.

Trials to demonstrate repeatability are critical and depend on all stakeholders to meet the project performance objectives.

Applying the data collection stage of CIT (Flanagan, 1954) and the DLC-IM initial topics can be identified and assessed by FMEA and WS-TP analysis.

FMEA

The initial FMEA identified 99 topics of which 34 topics showed RPN ≥ 100. The analysis is summarised in table 119 (appendices E.1.1). The example (table 47) examines the impact of the change process on repeatability.

Table 47: Repeatability: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Repeatability								
	Project Change	Delivered product does not meet requirements	8	Group members avoid raising change requirements	5	Management review	5	200

WS-TP

WS-TP analysis is summarised in tables 120 (appendix E.1.2). The example is continued in table 48. Analysing the repeatability activity demands understanding of detail. It is intended to represent the basis of a production process.

Table 48: Repeatability: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Repeatability							
	Project Change	Delivered product does not meet requirements	Group members avoid raising change requirements	Management review	200	Complexity of a change issue emerges and increases over several review meetings	Progress of the change issue impacts task delivery – particularly if on the critical path.

The analysis identified the impact of activities on critical topics, and showed that events occurring early in the task can influence the outcome. Project change events are clearly influential and managing then is important. Early detection resolution is critical, particularly in a specific customer focused task.

Topic 2: Requirements Specification

Development of detail requirements to form the basis of the production process.

Experience from repeatability trials and gained from process analysis.

Applying the data collection stage of CIT (Flanagan, 1954) and the DLC-IM initial topics can be identified and assessed by FMEA and WS-TP analysis.

FMEA

The initial FMEA identified 54 topics of which 23 topics showed RPN ≥ 100. The analysis presented in table 121 (appendices E.2.1). The example (table 49) examines the learning process.

Table 49: Requirements Specification: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
requirements								
	Learning from experience	Experience does not translate - delay caused by time spent on benefits management earlier in task	4	How does initial analysis translate to full analysis later in the project?	4	None	10	160

Learning to rapidly promote benefit and minimise negative effects contributes to the worth of the task / project. DLC-IM analysis can be applied to ensure this is managed and does not waste resource.

WS-TP

WS-TP analysis is summarised in table 122 (appendix E.2.2). The example is continued in table 50.

Table 50: Requirements Specification: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Requirements							
	Learning from experience	Experience does not translate - delay caused by time spent on benefits management earlier in task	How does initial analysis translate to full analysis later in the project?	None	160	"We had that problem on the XXX project" – requirements on current project inherit historical requirements and impose the same problems without development learnt from previous projects.	Multiple problems are identified as similar to previous projects – similar requirements are applicable to this project with similar problems and no solution model.

Recognising where prior experience is relevant and appropriately applied. Incorrectly applied is likely to cause more problems.

The WS element needs to test relevance and the TP to test any increasing trend in problems.

Output from previous TRL's and review of repeatability trials allows requirements to be developed as the research activity progresses towards definition of a production standard process at the subsequent TRL's.

Topic 3: System selection

Fundamental decision needs to be made early enough in the project, but the necessary info is minimal early on. How do you make the right decision?

Applying the data collection stage of CIT (Flanagan, 1954) and the DLC-IM initial topics can be identified and assessed by FMEA and WS-TP analysis.

FMEA

The initial FMEA identified 99 topics of which 35 topics showed RPN ≥ 100. The analysis presented in table 123 (appendices E.3.1). The example (table 51) examines. If the cause of the issue is the rate of progress of sub-contractors, then the problem is recognising this and applying mitigation before it adversely affects the task.

Table 51: System selection: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
System Selection								
	Top Management Support	Task progress is delayed – impacting overall project delivery potentially leading to failure	7	Sub-contractors top management focus on higher value work – delivery to task requirements becomes 'last minute'	6	Sub-contractor contract / Trials plan	5	210

WS-TP

WS-TP analysis is summarised in table 124 (appendix E.3.2). The example is continued in table 52.

If the prime contractor is challenged on progress in the early stages that this can be taken as a WS, e.g. not seeing sufficient progress on software development, such that initial demonstration is at the customer review.

Table 52: System selection: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Points
System Selection							
	Top Management Support	Task progress is delayed – impacting overall project delivery potentially leading to failure	Sub-contractors top management focus on higher value work – delivery to task requirements becomes 'last minute'	Sub-contractor contract / Trials plan	210	Top management (sub-contractors) clearly focuses on other priorities, adversely impacting the systems selection process	Resources are allocated to other priorities – lack of focus on systems criteria

A key characteristic of the TRL process is its progressive maturity. TRL5 represents the transition from research towards industrial process definition. System selection is key and correct choice needs to consider all relevant dimensions.

Topic 4: Hardware and Software development

Applying the data collection stage of CIT (Flanagan, 1954) and the DLC-IM initial topics can be identified and assessed by FMEA and WS-TP analysis.

FMEA

The initial FMEA identified 108 topics of which 36 topics showed RPN ≥ 100. The analysis presented in table 125 (appendices E.4.1). The example (table 53) examines the change process.

Identifying detail requirements and promoting confidence that all requirements have been captured and that the design solution meets requirements.

Table 53: Hardware and Software development: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Hardware and software development								
	Project Change	Delivered product does not meet requirements	8	Group members avoid raising change requirements	5	Management review	5	200

WS-TP

WS-TP analysis is summarised in table 126 (appendix E.4.2). The example is continued in table 54, and identifies early signs of requirements change and adverse impact of change.

Table 54: Hardware and Software development: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Hardware and software development							
	Project Change	Delivered product does not meet requirements	Group members avoid raising change requirements	Management review	200	Hardware and software design requires additional data – impacting schedule	Need to revisit hardware and software design

Development of hardware and software cannot be underestimated. Challenging any assumptions and change requests is reasonable as they have potential for significant adverse impact.

Topic 5: Condition of supply analysis

Examines the supply of components and sub-assemblies to a production line and impact on application of research activities.

Applying the data collection stage of CIT (Flanagan, 1954) and the DLC-IM initial topics can be identified and assessed by FMEA and WS-TP analysis.

FMEA

The initial FMEA identified 170 topics of which 59 topics showed RPN ≥ 100. The analysis presented in table 127 (appendices E.5.1). The example (table 55) examines impact of technology.

Identifying technology issues in early design reviews is critical to avoiding significant rework.

Table 55: Condition of supply analysis: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Condition of supply								
	Technology	Loss of contract	7	Inappropriate technology to meet requirements – e.g. customer EHS and legislative compliance	6	Requirements / contract review Compliance review at bid stage	4	168

WS-TP

WS-TP analysis is summarised in table 128 (appendix E.5.2). The example is continued in table 56.

Early review of detailed requirements.

Table 56: Condition of supply analysis: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Condition of supply							
	Technology	Loss of contract	Inappropriate technology to meet requirements – e.g. customer Environmental Health and Safety and legislative compliance	Requirements / contract review Compliance review at bid stage	168	Technical solution not fully defined or needs review	Technical solution not available within prime / sub contractor – requiring additional sub-con

Achieving the required condition of supply from contractors is critical, due to the impact of resolving issues that may be discovered late in the process.

Topic 6: Customer demonstration

Activities required to support demonstration to achieve customer acceptance.

Applying the data collection stage of CIT (Flanagan, 1954) and the DLC-IM initial topics can be identified and assessed by FMEA and WS-TP analysis.

FMEA

The initial FMEA identified 111 topics of which 38 topics showed RPN ≥ 100. The analysis presented in table 129 (appendices E.6.1). The example (table 57) examines project controls.

Resolving uncertainty to introduce process change at a fully defined level prior to customer demonstration is challenging.

Table 57: Customer demonstration: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Customer Demonstration								
	Project Control / Process	Uncertainties remain unresolved leading to requirement for significant corrective action	7	Project control / process does not accommodate uncertainty – insufficient contingency	6	Design review	5	210

WS-TP

WS-TP analysis is summarised in table 130 (appendix E.6.2). The example is continued in table 58.

Accommodating uncertainty within the demonstration activity needs to be resolved early.

Table 58: Customer demonstration: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Customer Demonstration							
	Project Control / Process	Uncertainties remain unresolved leading to requirement for significant corrective action	Project control / process does not accommodate uncertainty – insufficient contingency	Design review	210	Uncertainties not resolved during initial planning / no process to resolve	Uncertainties remain unresolved at point of commitment to demonstrations

Critical to progress to the next stage of the TRL process. Customer demo is the focus of development and provides the foundation of the development of an industrialised process.

5.4.2 Case study (4): Discussion

The focus for this stage of the TRL maturity process is the demonstration of a process to the customer that the key characteristics have been captured and that the research shows that the requirements can be controlled by the proposed process.

5.5 Case study (5): Research project (part 2), Industrialisation

This case study develops the previous study by examining progress of the research project to the next technology readiness level. In this case the project was active and the analysis was used to examine the progress of the tasks as the project progressed towards delivering TRL 6.

Within the case study the CIT (Flanagan, 1954) stage of collecting data was applied and a range of topics were identified, and an example is presented and discussed.

The success / failure criteria are examined to identify examples of ‘potential effects of failure’, and to test the relevance to project performance. This also provides initial analysis as required by the CIT (Flanagan, 1954). Further analysis is given at the end of the case study and in chapter eight.

5.5.1 Summary of case study

Topic 1: Legislative and Environmental, Health and Safety review

Developing the detail production process must also meet all relevant legislation and EHS regulations.

Applying the data collection stage of CIT (Flanagan, 1954) and initial topics can be identified and assessed by the DLC-IM including FMEA and WS-TP analysis.

FMEA

The initial FMEA identified 25 topics of which 15 topics showed RPN ≥ 100. The analysis presented in tables 131 (appendices F.1.1). The example (table 59) examines technology.

Impact of project changes and EHS reviews

Table 59: Legislative and Environmental, Health and Safety review FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	SEV	Potential Cause(s) / Mechanism(s) of Failure	OCC	Current Process Controls	DET	RPN
Legislative and Environmental, Health and Safety review								
	Technology	Environmental, Health and Safety or legislation impacts intended technology use	5	Legislation and Environmental, Health and Safety requirements require additional changes to the application environment	6	Review of applicable Environmental, Health and Safety regulations and legislation with respect to application environment	4	120

WS-TP

WS-TP analysis is summarised in table 132 (appendix F.1.2). The example is continued in table 60.

Design reviews and ensuring legislation is met due to changes

Table 60: Legislative and Environmental, Health and Safety review WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Legislative and Environmental, Health and Safety review							
	Technology	Environmental, Health and Safety or legislation impacts intended technology use	Legislation and Environmental, Health and Safety requirements require additional changes to the application environment	Review of applicable Environmental, Health and Safety regulations and legislation with respect to application environment	120	Technical design reviews identify Environmental, Health and Safety or legislative issues which need to be resolved	Legislative or Environmental, Health and Safety issues lead to design change requiring additional resource from or additional to management reserve

Research activities must meet EHS legislation and must ensure that the proposed technical solution also meets legislation.

The focus is to demonstrate a proposed process that meets all requirements including EHS. Introduction of new technology is a specific issue. The potential for technology to automate a manual process requires the intuitive features to be measured by the proposed process. This opens a new set of challenges that need to be assessed for potential adverse impact. The ‘technology’ example examined here highlights the problem.

Topic 2: Requirements and Specification review

Review requirements and specification to maximise benefits. Early recognition of issues is needed.

Applying the data collection stage of CIT (Flanagan, 1954) and the DLC-IM initial topics can be identified and assessed by FMEA and WS-TP analysis.

FMEA

The initial FMEA identified 105 topics of which 46 topics showed RPN ≥ 100. The analysis presented in table 133 (appendices F.2.1). The example (table 61) examines

Table 61: Requirements and Specification review: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Requirements and Specifications Review								
	Benefits Management	Loss of contract	8	Failure to identify contract benefits and link them to requirements	5	None	10	400

WS-TP

WS-TP analysis is summarised in table 134 (appendix F.2.2). The example is continued in table 62.

WS-TP to detect early stage of a requirement and specification not being met, or scope / resource creep eroding the expected benefits.

Table 62: Requirements and Specification review: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Requirements and Specifications Review							
	Benefits Manage ment	Loss of contract	Failure to identify contract benefits and link them to requirements	None	400	Resource creep	Beneficial topic not included in task review

The stage of the research process focuses on development of detail process requirements and specifications to a level of detail to define the basis of a production process. Failure to demonstrate requirements and specification can be met risks loss of contract. Detailed review is needed to recognise where performance issues start to diverge and fail to support process integration.

Topic 3: Supply chain qualification

Issues often arise within the supply chain. This task challenges the process of qualifying the supply chain to ensure it delivers the requirements.

Applying the data collection stage of CIT (Flanagan, 1954) and the DLC-IM initial topics can be identified and assessed by FMEA and WS-TP analysis.

FMEA

The initial FMEA identified 84 topics of which 26 topics showed RPN ≥ 100. The analysis presented in table 135 (appendices F.3.1). The example (table 63) examines top management support, and the need for constructive action to ensure that sub-contractors requirements are understood and appropriate solutions are developed.

Table 63: Supply chain qualification: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Supply chain qualification								
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	8	Lack of priority from top management for supply chain qualification activities	5	Not communicated by top management	5	200

Product qualification analysis at an early stage to ensure development direction meets requirements and does not emerge as a critical issue.

WS-TP

WS-TP analysis is summarised in table 136 (appendix F.3.2). The example is continued in table 64.

Table 64: Supply chain qualification: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Supply chain qualification							
	Top Manage ment Support	Contractor management don't prioritise project tasks leading to delay or project failure	Lack of priority from top management for supply chain qualification activities	Not communicated by top management	200	Requirements for qualification of product delivered by supply chain is not defined by top management	Late definition of requirements leads to additional work and prompts change to project baseline

Further analysis to validate proposed supply chain to ensure all requirements are demonstrated and the supplied items integrate to the process.

Topic 4: Full Process demonstration

Presenting the process development commensurate to the TRL.

The objective is to provide practical evidence that the process definition meets all requirements.

Applying the data collection stage of CIT (Flanagan, 1954) and the DLC-IM initial topics can be identified and assessed by FMEA and WS-TP analysis.

FMEA

The initial FMEA identified 76 topics of which 22 topics showed RPN ≥ 100. The analysis presented in table 137 (appendices F.4.1). The example (table 65) examines project change in the context of full process demonstration.

Does the process demonstration show sufficient development from previous TRL, and is it comprehensive enough to proceed to the next TRL?

Table 65: Full Process demonstration: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Full process demonstration								
	Project Change	Delivered product does not meet requirements	8	Group members avoid raising change requirements	5	Management review	5	200

WS-TP

WS-TP analysis is summarised in table 138 (appendix F.4.2). The example is continued in table 66.

Table 66: Full Process demonstration: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Full process demonstration							
	Project Change	Delivered product does not meet requirements	Group members avoid raising change requirements	Management review	200	Product requirement not met leading to change request which is not raised	Previously rejected change request is required

Careful analysis of change requests and their applicability. Also, other topics not recognised formally

Full demonstration of the process as a prototype of a production standard with all requirements captured and key characteristics.

Topic 5: Design review

Design review integrates results of the process demonstration and reviews the complete proposal and its applicability to the product and manufacturing environment.

To review proposed process and evidence to support the decision to progress to the next TRL, introduction to manufacturing.

Applying the data collection stage of CIT (Flanagan, 1954) and the DLC-IM initial topics can be identified and assessed by FMEA and WS-TP analysis.

FMEA

The initial FMEA identified 82 topics of which 26 topics showed RPN ≥ 100. The analysis presented in table 139 (appendices F.5.1). The example (table 67) examines the impact of project change.

Table 67: Design review: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Design review								
	Project Change	Delivered product does not meet requirements	8	Group members avoid raising change requirements	5	Management review	5	200

WS-TP

WS-TP analysis is summarised in table 140 (appendix F.5.2). The example is continued in table 68.

Table 68: Design review: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Design review							
	Project Change	Delivered product does not meet requirements	Group members avoid raising change requirements	Management review	200	Change requests do not cover known issues	Design review action to resolve

Design review validates the process and authorises progress to the next TRL stage.

Ensuring all topics are covered requires ongoing analysis through the research. Prediction is critical to this activity.

5.5.2 Case study (5): Discussion

This case study focused on the continuing development of a research project and the need for proactive analysis of potential deviations. The activities examined were closer to active application of the research model, as the case study was an ongoing task at the time of analysis.

Whilst not conducted as a formal assessment of the research tasks performance, the work carried out for this case study influenced progress of the task by challenging the activities and design review. For example, by developing the focus on requirements definition and the scope of work being placed in the supply chain.

5.6 Industrial investigation discussion

Chapter four identified the research question:

> How can predicting task deviation positively influence improved project performance?

The case studies examine this from different perspectives, both individually and collectively.

CS 1 – linked the research model to the initial theoretical position by testing against pathogens.

CS 2 – develops focus on single tasks and demonstrates that topics that caused problems could be predicted and mitigation defined.

CS 3 – Developed potential for industrial application

CS4 and CS 5 developed towards practical application by examining recent and currently active stages of a research project.

Use of CIT (Flanagan, 1954) to collect data and conduct analysis provided a method of focusing on the detail with in the case studies.

Use of Case study

The objective of the industrial investigation was to illustrate the application of the research model and examine its potential to improve project performance. The five case studies examined provide a collective view that progressively tests the potential application of the research model.

The number of individual lines of application (2251, Table 10) provides a data base from which further investigation and application to active projects can be developed. The level of analysis carried out meets Flanagan's (1954, page 18) suggestion of the necessary number of incidents to allow conclusions to be discussed.

In summary the investigation suggests the research model could be applied to further cases.

6 Discussion

6.1 Introduction

This research set out with the aim of investigating project performance, focused on the delivery of project objectives. This section examines the "*Answer RQ / Prove Hypothesis*" and "*Evaluation of Research Quality*" stages of Albores-Barajas (2006, page 40). Following Alvesson and Sandberg (2011) it is also necessary to review the case studies by "*Considering it in relation to its audience*". This chapter examines whether the research addressed the research aim and research question.

6.2 Research framework analysis

This section examines the broad research framework and the first part of the research aim: To investigate issues underlying project failure and how tools and techniques to predict performance emerge from project management's theoretical foundations.

The literature analysis in chapter two provided the foundation to develop the overall research framework in chapter four, and recognised the need to investigate the location of project management on the scientific spectrum (Smith 2009).

The body of knowledge is formulated, in the practitioner context, by documents published by the various professional organisations (APMBoK, PMBoK, discussed in section 2.7). Analysis of the relevance of these documents to fundamental theoretical research (Morris et al., 2006; Hanisch and Wald, 2011) suggests they lack relevant underpinnings to provide a sound basis for research.

This prompts a need to identify a relevant body of knowledge within which knowledge gaps could be identified. This body of knowledge is recognised in more general terms as the community paradigm (Kuhn 1996), leading to the challenge of identifying anomalies or knowledge gaps.

This dictated that an initial analysis of the scientific foundations of project management was needed. The initial investigation to position the research identified fundamental issues with the lack of community paradigm. In this respect, 'normal science' in the sense described by Kuhn (1996) could not be applied. The recognition of the lack of a community paradigm (sections 2.5 and 2.6) prompts research based on problematisation.

The assessment indicated the view that project management blended both social sciences and natural sciences approach to process analysis. However, the critical issue of defining, having control over, and therefore the opportunity to influence, the 'end game' is a fundamental difference. The argument presented was that this aligned project management to design science (Simon, 1996), which was supported by the view that project management was a sub-field of the management sciences (Söderlund, 2011) and that management science should be located in design science (Tranfield 2002b) .

The development of the research challenges the 'gap spotting' approach by applying '*problematization*' (Alvesson and Sandberg, 2011) and is consistent with the design science approach. It does locate within the overall scientific research spectrum presented in figure six. This framework provides the basis for analysis of issues identified in the literature and derivation of the research topic by challenging the underlying assumptions of the field.

The aim of the research was "to investigate issues underlying project failure and how tools and techniques to predict performance emerge from project managements theoretical foundations". This can be considered in two parts:

- Issues underlying project failure:-
  It is clear from the literature review that the lack of community paradigm is a significant factor in project failure. Without the community there is no foundation against which performance can be tested and positive performance mechanisms developed.

- The lack of theoretical foundation makes it difficult to identify how tools and technique emerge. It would appear most are developed through practice, but lack of community paradigm restricts the potential for these to be tested for their contribution to performance.

The conclusion was that an alternative approach was needed to allow a research topic to be identified.

The investigation identified issues underlying project failure. It identified that tools and techniques were largely ‘mechanistic’ and focused on status reporting. There was little to show tools and techniques emerging from project managements theoretical foundations, due to the lack of theoretical foundations.

From the functional analysis of the project process ‘prediction’ was recognised as a missing function. This was examined and the DLC-IM developed and examined.

The two key topics that develop the framework are:

- The potential for design science to contribute to the development of a community paradigm
- The development of FMEA to test performance

The potential role of these two topics is examined in the next two sections.

The initial bounding of the research was to focus on tools and techniques rather than people issues. From the perspective of tools and techniques the research has identified the need to investigate prediction as a project function and has proposed a predictive tool. It is clear that the application of the tools and its practical benefit to project performance has a ‘social’ aspect and further work would need to incorporate the actor’s perspective in the process of applying the tool, using it for the purpose of detecting early stage deviations, and learning from it to improve future task performance. The ‘social’ aspects were always going to lie outside the scope of the work, if for no other reason than the author’s lack of experience in the field of research into social behaviour.

Developing a more focused assessment of the key issues raised in the research the following sections examine design science as the potential foundation of a community paradigm and failure modes and effects analysis, weak signals and tipping point as the basis of the research model to investigate the potential for performance prediction.

6.2.1 Design science

This section examines design science as a candidate for the basis of developing a community paradigm.

The initial aim of this research was to investigate project performance and methods of improvement. In attempting to locate the scientific foundations it was clearly established that the lack of community paradigm (Kuhn, 1996) was a fundamental issue (section 3.5). The problem is widely recognised; e.g. Koskella and Howell (2001, pages 8-9), Söderlund (2004a, page 184), Smyth and Morris (2007, page 423), Kwak and Anbari (2009, page 436).

As the investigation progressed, the potential for design science as a basis for project management emerged (Tranfield, 2002b, page 409; Söderlund, 2011) as well as specific statements (Ahlemann, 2013; Cioffi, 2006). Design science, in the contemporary form, was introduced by Simon in 1969 (3rd edition:1996), as discussed in section 2.2.3.2. Investigation of the industrial sectors identified that all had a design science 'school of thought' (table 69).

Table 69: Examples of design science literature relevant to project management in various industrial sectors

Industry Sector	Design Science application in the sector
Engineering	Micaëlli et al. (2013)
Construction, Building and Civil Engineering	Voordijk (2009) characterises construction management and economics as a multidisciplinary design science.
Software, IT, Telecom and Computers	Iivari (2007) discusses information systems as a design science
Healthcare	Bevan et al. (2007) take a design science
Chemical Systems, Chemical Engineering, and Oil and Gas	Dougherty and Dunne (2012) discuss the development of chemical compounds with reference to Simon (1996)
Power, Energy Production, and Energy Systems	Bodenbenner et al. (2013)
Environmental and Sustainability	Komenda and Schwarz (2013)
Biotechnology and Pharmaceutical	Derelov et al. (2008) consider application of design science to Bio-Mechatronic products
Space, Aerospace and Aircraft Engineering	Bloebaum and McGowan 2012 discuss the need for a design science
Defence	Bloebaum and McGowan 2012 could also be argued to be applicable to defence.
Transport	Arnas et al. (2013)
Electronics	Pereira and Mire Da Silva (2012) reference Simon (1996)
General Management and Business	Ghazarian (2013)

Role of design science in project management

Building on the discussion in chapter two, it is also appropriate to consider the alignment of industrial sectors to design science.

Voordijk (2009, page 718) characterises construction management and economics as a multidisciplinary design science, summarised in figure 27.

Voordijk (2009, page 718) argues the need for Sciences and Humanities inputs to design science (see (1) in figure 27) and that "*The design mode of knowledge production is the common ground on which research in construction and management can meet*" (see (2) in figure 27). Voordijk (2009) discusses the epistemological position in the context of construction management and economics and concludes 3 outputs (see (3) in figure 27).

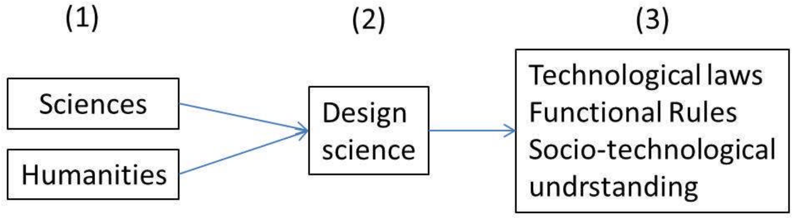

Figure 27: Design Science (Voordijk, 2009, page 718)

Another major sector using project management is Software, IT, Telecom and Computers including hardware and software. Hevner (2004) and Iivari (2007) reviewed the application of design science to the information systems environment. One contribution is Gregor and Hevner (2013). They identify design science research as "*an important and legitimate Information Systems (IS) research paradigm*" Gregor and Hevner (2013, page 337).

To illustrate the broadening conceptualisation (as concluded by Winter et al., 2006), project management has developed within healthcare. Mettler and Rohner (2009) examine maturity models in healthcare using a design science perspective. Bevan et al. (2007) take a design science philosophy applied to resolving health care issues.

In summary, analysis of a range of industrial sectors shows that:

- Project management is applied across a broad range of industries
- No industry stands out as being a distinct leader or accomplished employer of project management
- Individual industries have their specific areas where specialist knowledge and experience are necessary, but the underlying principles are broadly common
- Design Science can be associated with most industrial sectors that utilise project management.

Potential basis for a project management community paradigm

The discussion has examined design science as a potential foundation for a project management community paradigm. If 'design science' is the science of production, with a distinctive underlying philosophy to that of the natural and social sciences, then the basis of positioning a community paradigm for project management emerges. It has also been identified that numerous industrial sectors that employ project management also have a design science 'school of thought'. If projects are associated with production (Bredillet 2007a, page 4;

2010c page 4; Flyvbjerg, 2014), then it can be concluded that the initial stage of defining the end game is a critical difference.

The interest in design science appears to be increasing: of 4,354 articles (Scopus search, December 2013) that cited Simon (1996), 1,495 of them were published since 2010 suggesting an increasing interest in this field.

Conclusion

There is a strong suggestion that the design sciences provide a suitable location for the management sciences and that project management is recognised as a sub-field. The designed nature of the objectives of management in general and project management specifically have been recognised. There is a clear industrial interest in design science. This should be examined as further work.

Summary

- Project management has a logical location in design science
- Industrial sectors have a design science school of thought

Therefore there is potential for alignment between a design science based project management community paradigm and the industrial sectors design science school of thought. Investigation of this alignment may lead to a better understanding of project management process and its application in practice.

6.2.2 Research question discussion

This section examines how the derivation of the research question relates to the issues identified in the initial discussion / literature review and if the industrial investigation contributes to answering the research question.

The research question was:

> How can predicting task deviation positively influence improved project performance?

This can be examined in two parts:

- Considering the prediction of task deviation
- Its influence on improved project performance

Recognising the overall track record of performance failure in projects, the initial need was to investigate the scientific foundations of project management, it location on the scientific spectrum and its community paradigm.

The lack of community paradigm meant there was no basis to apply ‘normal science’ as defined by Kuhn (1996). This did not allow knowledge gaps to be identified. This prompted the need to challenge underlying assumptions (By ‘Problematization’ Alvesson and Sandberg, 2011) and directed the investigation of the research focus toward more fundamental topics. The argument being that if projects exist to deliver their defined objectives then their performance must be the critical metric.

Research must then focus on performance improvement, but locating a research focus became a challenge due to the lack of framework on which to locate and define the issue. The functional analysis allowed prediction to be identified as a missing function, which when developed to focus on single tasks, allowed task deviation to be examined.

By examining this focus, useful research could be conducted that led to a contribution to knowledge, but also reinforced the need to further investigate the community paradigm for which design science (Simon, 1996) is proposed as a candidate. On this basis, the research question met its objectives.

6.2.3 FMEA as Performance analysis tool

FMEA was used as it is a recognised tool that met the requirements of the research model. Although it has some issues, it can be effective. Further development of ‘performance FMEA’ might be useful.

The need for the research model was an initial analysis process that would be conducted prior to the start of work on the project task.

Failure Modes and Effects Analysis (FMEA) is such a process. Traditionally applied to product and more recently to process, this provided a suitable mechanism for the research. However, it was necessary to apply FMEA to test expected performance and identify potential performance failures in the task plan.

Whilst this extends the application of FMEA, issues that are recognised in traditional application need to be considered:

- Relevance of RPN.
  - Not all RPN values can be achieved
  - What level to set the cut off?
  - Does RPN hide issues? (e.g. S=10, O=2, D=2 RPN = 40 which would suggest no action is required, but S=10 could be significant).

- How personnel behave when doing FMEA – can be time consuming, consistency can be challenging.

As a mechanism for structuring an approach to identifying potential issues and filtering them in order to select the more critical ones, the basic model has achieved that objective. This is, however, the role that FMEA is expected to apply to an investigation. The analysis presented here extends the application of the FMEA concept to ‘performance’ rather than its traditional domains of ‘product’ and ‘process’. The development of the research model to include WS and TP provide a mechanism to examine the detection of a deviation emerging at an early stage and the criteria by which the mitigation plan may need to be applied. The structuring of the case studies can be summarised:

- The commonality of the initial criteria was critical to provide a common baseline allowing comparison across the different case studies.

- This also showed that different case studies and specific tasks generated a range of topics that required investigation.
- Whilst the early case studies were retrospective, where it is inappropriate to claim that topics were recognised ‘before the event’ the latter case studies moved towards active application where tasks had not been completed, so there was a real element of ‘before the event’ analysis.

6.2.4 Weak signals

Identifying and categorising priority of an issue via FMEA is the critical first step but no benefit is to be gained unless action is taken at the appropriate point.

Consideration of applying corrective action can only be relevant if there is evidence of the problem emerging.

Weak signals analysis allows the emergence of the problem to be identified prior to it becoming significant and adversely impacting performance.

The advantage of focusing on the emergence of issues at an early stage allows progress decisions to be assessed. This does develop a concern about the difficulty of detection.

6.2.5 Tipping point

Tipping point analysis provides a framework to define when issues become critical and corrective action needs to be applied, such that when weak signals show emergence of the problem identified by FMEA action can be effectively applied.

The challenge is defining the criteria when the tipping point has occurred, as the focus on early stage deviation when issues are, by definition, small.

6.3 Fieldwork methodology analysis

This section reflects on the application of the selected methodology, case studies and critical incident technique.

This section develops the investigation of the second part of the research aim; to conduct research that focuses on detailed analysis and structure required to identify failure sources and detection techniques and develop methodology to guide practitioners to achieve improved project performance.

6.3.1 Case study analysis

This section examines the use of the case studies technique to test the research model.

The primary objective of the case studies was to examine the application of the research model, which has the initial role of identifying topics that can be identified ‘before the event’ and could lead to ‘deviation’ and to test if a mitigation plan could be devised with an understanding of the WS that indicate the early stages of the emergence of the deviation, define the criteria by which the TP can be identified when the mitigation plan needs to be applied.

Overall, this approach showed potential for developing the concept of the research model. The challenge was to obtain relevant industrial application, as there was no pre-existing application or database on which to draw data. Consequently, the cases presented are only considered as illustrative of the potential application, and were based on general industrial experience.

6.3.2 Critical Incident Technique analysis

This section examines the use of critical incident technique in the investigation, and considers whether its combination with case studies provided a useful research method.

The critical incident technique provides a technique to focus on specific aspects of problem. In this research, based on the research model, the key characteristic was the identification of topics that addressed critical aspects of a tasks performance. The use of FMEA to test performance resulted in focus on specific aspects of the task.

Using CIT as part of the process was appropriate to focus on the potential impact of the stages of the research model.

In this respect it was reasonable to apply CIT at this level of detail.

6.4 Industrial investigation analysis

The structure of the case studies intended to develop the analysis of the research model by building on previous cases;

- The first case study (Coley, 2008) related to pathogens and showed a reasonable relationship
- The second case identified a single task and provides a basis for practice application
- Case study three examined a generic facilities development scenario and showed potential for broader application.
- Research (part 1) tested a different environment and extended towards an active project (research, part 2) in which testing the model showed that potential deviation problems could be identified.

The case studies presented are described as ‘illustrative’ of how the process might be applied in industry. Further work will apply the process in a more specific industrial situation.

Further activity to analyse the effect of the research model, to identify whether the process could have an effect, or whether the initial challenge changes the attitude of actors towards delivering the task and performance improves by increased awareness of the potential issues.

The DLC-IM, based on the FMEA/WS/TP approach will still be applicable as they test capability to deliver the task (or project) plan and therefore how the required performance is achieved.

It was not the intention of this research to validate the extension of FMEAs application to test performance (as opposed to the traditional applications of product and process). More work is required to focus on the potential of this application.

Combined with the discussion in chapter one covering the increasing role (i.e. broader conceptualisation) of projects there is emerging from this research a direction for further development of the DLC-IM research model to focus on capability (based on Bannerman 2013) as the basis of potential to deliver the required project performance.

If failure to learn from projects (Swann et al., 2010) is an issue, it is because little, or no, action is taken at the start of a project to identify and employ relevant 'lessons learnt'. The focus on performance analysis and deviation, specifically focused on 'prior to the event' modelling offers a formal process opportunity to apply lessons learnt from previous projects rather than relying on collective experience of those involved.

The analysis examines whether the criteria of the research model were achieved. Five case studies were identified. Within these five cases, thirty three topics were identified. Applying the seventeen success failure criteria resulted in 2,251 individual applications of the DLC-IM research model. The analysis of the initial applications resulted in 853 items where RPN ≥ 100 and detailed analysis using WS and TP was applied to develop a mitigation strategy.

Case study (1)

The initial case study was selected because there was documented evidence of the basis of the case study (Coley 2008). It was also developed to examine the relationship between the theoretical and industrial versions of the research model. The analysis question is:

- Was there reasonable alignment between the 'pathogens' model and the objective of the analysis?

It was possible to identify ‘pathogens’ and ‘incubation processes’ for all of the initial topics. Whilst further work would be needed to establish a rigorous relation between the two, for the purposes of this research, and the expectation to develop the case study analysis to focus on the DLC-IM, this level of analysis was sufficient.

Case study (2)

- Did the focus on a single task provide sufficient detail analysis to suggest the DLC-IM is a reasonable process?

This case study had the objective of testing the research model in a single task and an activity that would initially appear easily bounded. It could be seen from the analysis that a wide range of factors influenced the specific task. From this perspective, the DLC-IM tested the understanding of the installation process and identified topics that could impact the activity.

Recognising these topics allows mitigation to be developed. This indicates that the basic process is achieving its basic objective. However, it also highlights the ‘return on investment’ in terms of the effort required to conduct that analysis and whether that is appropriate to achieve the oven installation process.

Case study (3)

- Did the application in a generic industrial project suggest there is potential for practical industrial application?

FMEA is conducted widely in industry to examine product and process.

This analysis extends the FMEA to consider ‘performance’, the assessment of the potential to deliver the plan as published. This is an extension of a recognised industrial process.

Understanding the mitigation of identified issues is also recognised in industry, although the specifics of ‘WS’ and ‘TP’ might be a new area, although the objective should be generally recognised.

Case study (4)

A research topic provides an opportunity to examine the potential of the process in a dynamic environment – the point of research projects is that they develop through their lifecycle. This allows the potential of the process to be tested.

Case study (5)

This case study develops the previous case study towards a more focused application of an active project task.

At this point, the previous case studies have developed and investigated the potential application of the research model. This case study extends the application boundary by focusing more on the active task.

6.5 Test for research Quality

It is appropriate to review the ‘quality’ of the research. Yin (2009, page 40) offers some tests for research quality:

- Construct Validity
- Internal Validity
- External Validity
- Reliability

Considering these topics, construct validity examines if the research model aligns with the philosophical approach adopted in chapter 2. The use of the model developed by Albores-Barajas, (2006, page 40) provided detailed methodology. Its development by mapping onto the V model presented by Rook (1986) provided consistency across the methodology. This provides the consistent overall process and supports development of the research process model. Internal validity asks if the research model consistent within the project management environment. The process model presented in figure 13 illustrated one approach to the project management process. The integration of the research model in figure 24 indicates that the approach is consistent. External validity examines if case studies and CIT work together. This appeared acceptable when a common reference is applied to the case studies. In this investigation a common set of criteria were applied to each case. If there were not common, then it would be difficult, in not impractical, to identify critical incidents in different cases and to apply any common form of analysis. The final topic, reliability, examines if the data indicates that the model is reasonable. Given that there is consistency across the case studies, and CIT could be applied, it suggest that the research is basically reliable, although it is recognised that the research was illustrative of the process and further work (discussed in chapter nine) is needed to develop and validate the process.

6.6 Discussion

The analysis considers if the industrial research contributes to answering the research question, in the context of the research aim.

The basic challenge to analysing any activity is to establish the control group against which the test group can be measured. In a project management activity it is difficult to replicate the same task twice, due to the wide range of influences on its performance, particularly as it exists in an open system.

It is reasonable to argue that the research model could challenge actors to examine the potential performance issues prior to commencing work. This is part of the function of applying FMEA. This could lead to modifying the task plan, or developing a mitigation plan, as was the intended role of WS-TP analysis. The objective of the research model was that this would then lead to pre-emptive action to detect early stages of deviation and minimise the adverse impact of a deviation maturing.

The difficulty in analysing the effect of the research model is whether improvement occurred due to application of the model or if it was a case of good management or just applying a dose of common sense.

This section considers how case study and CIT related to the second part of the research aim; ‘to conduct research that focuses on detailed analysis and structure required to identify failure sources and detection techniques and develop methodology to guide practitioners to achieve improved project performance'.

Developing from the range of issues identified in the initial research, the challenge was to identify a relevant research focus.

Chapter four developed the initial literature investigation by applying the 'problematization' approach (Alvesson and Sandberg, 2011) and following the functional analysis, defined the research question. This identified the unit of analysis as 'deviation', being the difference between the planned and actual delivery of the task. Following assessment of the fieldwork methodology in chapter five, development of the research model in chapter six led to the research model. The allowed the research to offer an opportunity to reduce the level of 'deviation'. The case studies, and use of critical incident technique, illustrated the potential of the research model to test a project task for performance.

The more general contribution from this work recognises the lack of community paradigm which provides an explanation of why project management has an ongoing level of reported failure. Lack of development of a community paradigm may relate to the lack of evidence of improving trends in delivery performance.

The focus on performance prediction led to the development of the deviation lifecycle model and the extension of FMEA to examine performance and in combination with weak signals and tipping point to the industrial research model, which is discussed further in section 7.5.

7 Conclusions

This chapter finalises the research by examining the "*Drawing conclusions*" and "*Continuous assessment / improvement of the model*" stages of Albores-Barajas (2006, page 40). It also examines the final stage of Alvesson and Sandberg (2011) "*Evaluating the alternative assumption ground*".

The research process and topics examined to support the investigation and conclusions are discussed with a summary of the contribution to knowledge.

7.1 Research methodology

Investigation of research methodology presented the integration of the 'V' diagram (Rook, 1986, page 11) and Albores-Barajas (2006, page 40) to provide the basis of an overall research methodology. The V diagram provides a visual representation of the decomposition of the subject towards a research focus followed by integration towards general theory. In this respect it was beneficial in providing a visual prompt of the need for research focus.

The topics defined in the process by Albores-Barajas, (2006, page 40) were developed from Meredith (1993). It could be debated as to whether they were the right set of topics, and whether some should be deleted or new topics added. The sequence of the topics could also be challenged. To some extent there was a structuring of the research to follow the 'formula'. It could be argued that the order of some topics could be developed and some flexibility introduced to follow a generic process that would allow more challenging research. Overall this provided a structure across the thesis that ensured all sections followed the process in a manner that was intended to contribute to academic rigour.

7.2 Research topic

Early recognition of the issues with the lack of community paradigm prompted the examination of the relationship between basic scientific principles and project management.

The linkage between basic scientific principles and project management did not appear to be recognised in literature (or via text books). The scientific foundation was examined in terms of project management being a sub-set of the management sciences (Söderlund 2011) and the view that management science should be treated as a design science (Tranfield 2002b). This provided a position for project management on the scientific spectrum and identified the potential for design science as the foundation of a community paradigm. The potential role of design science is discussed further in section 9.3. Whilst chapter two investigated this area, it was not possible to explore this fully within the scope of this research. This is considered in the further work discussion.

Having identified this location, it was then necessary to develop an understanding of the current ‘community paradigm’ and develop the research focus. The lack of community paradigm challenged the potential to identify research issues by ‘gap spotting’. Without the recognised foundations of an accepted community paradigm, there is little between which knowledge gaps can be identified. Challenging arguments and assumptions (‘*Problematization*’, Alvesson and Sandberg, 2011) was identified as an appropriate method to identify research issues. Hällgren (2012) argued, specifically in the context of project management research questions, that ‘gap spotting’ would not identify ‘interesting’ questions and might reinforce potentially wrong arguments.

Since 1995 the ‘temporary / unique’ perspective has been widely applied. This has been criticised by its original author (Packendorf 2002), it has not led to any recognisable improvement in project performance has been argued to be wrong (Morris 2013a, page 116). Alternative terms are needed, and further work is urgently required in this area. The multiple ‘schools of thought’ demonstrate the pre-paradigm nature of project management, and until there is a consensus on either a specific school, or potentially a multiple perspective, then ‘normal science’ in the sense of Kuhn (1996) cannot commence.

As a general examination of project performance, the primary issue that emerged from the literature review was to understand why projects might go off plan, i.e. deviate. Literature review showed that little, although significant, work had been carried out in this area. (Hällgren, 2012).

Further review of the issues, specifically identifying the functional approach, developed the view that ‘prediction’ was a missing function within the project management ‘toolset’. Most project management performance analysis is post event, so cannot influence performance of the current project.

Leading to the research question:

How can predicting task deviation positively influence improved project performance?

This required an initial analysis of the concept of ‘deviation’ illustrated by a project activity not taking a straight line from start to finish. To support the focus of the research, it was decided to apply this to individual project tasks.

7.3 Research model

The examination of tasks required a method to test performance potential, and identify sources of failures, which could be applied prior to the event. This prompted in the investigation of ‘pathogens’ and ‘incubation periods’ (Busby and Hughes, 2004) as an early stage of investigating and mitigating potential deviations. This allowed the concept of the ‘deviation lifecycle’ to be constructed, and the argument that the process by which activities might go off plan and be corrected could be considered as a lifecycle function of a project task. The term deviation lifecycle, and a range of variations, were examined to identify existing literature. None was found. This offered the opportunity to develop a research model that could examine the deviation lifecycle and develop it to a process that had potential for industrial application.

FMEA was selected, as it fulfilled the need and is a recognised process in industry. It is however, recognised that there are numerous issues with the application of FMEA. These are outside the scope of this research, but it is recognised that alternative techniques might offer a process improvement and these could be investigated as further work. The key aspect being that the initial analysis is conducted prior to commencing work on the activity.

The FMEA has the advantage of analysing the potential for these deviations to have a significant impact on the task performance. This provided an initial filtering process to select the priority tasks for further analysis. It is however, a feature of FMEA that continuous review of the issues should be conducted to identify changes in priorities, including elimination of resolved issues and introduction of new ones, throughout the task lifecycle.

Issues identified from the initial activity are then assessed to identify the probable events by which the might emerge (i.e. WS). Alternatively, the ‘early warnings’ (EW) literature could be examined for this function. Application of ‘TP’ analysis allows criteria to be identified as to when a mitigation plan should be applied. It is not always the case that the resolution of a potential issue should be applied immediately.

Industrial investigation to apply the research model provided the next challenge. This was representative of potential industrial application and developed to illustrate how the research model might be applied. This is clearly an area in which further work is needed.

Whilst the research model only provided illustration of potential application, it does clarify the post project learning opportunity. It could be argued that the model formalises activities that should be carried out within the project, and may often be carried out instinctively or as a result of experience. The advantage offered is that the initial state, prior to commencing task work, is now documented and can be reviewed against actual outcome. Review of this nature allows learning to be applied to future projects. By this process, there is further potential for performance improvement by understanding the topics that require closer attention.

To test the potential relevance of the proposed research model (DLC-IM), the final two stages of Alvesson and Sandberg (2011) can be considered:

- *Part 5: “Considering it in relation to its audience”*
- *Part 6 “Evaluating the alternative assumption ground”*

These will be discussed in relation to the research model and illustration of its potential industrial application.

One of the points that was raised by Alvesson and Sandberg (2011), by reference to Davies (1971) regarding the ‘interesting’ nature of research, was that the research challenged some, but not all, of the underlying assumptions of the field. One way of testing this is to consider the Integration of research model with ‘integrated function set’ – developed from figure 13 in chapter 4.

The integration of the two models suggests the proposed DLC-IM research model is compatible with the suggested process model, and also that the research model meets the arguments of Davies (1971) and Alvesson and Sandberg (2011).

Davis (1971) developed by Alvesson and Sandberg (2011) argued that ‘interesting’ research should challenge some, but not all, underlying assumptions of a field. The research model developed here meets this approach. If the project management model discussed in chapter four (figure 13) provides the basis for integration of DLC-IM (chapter four, figure 24), then comparison between the two figures indicates that not all assumptions of the basic process have been challenged (figure 28).

Research model illustrates process integration at the project level.

This provides contribution for practice (for practitioners) by developing the overall process and integrating the performance prediction function.

- Illustrates a potential process model that integrates the functions identified as necessary within project management.
- Identifies where the performance prediction function identified in this research is located within the process model.

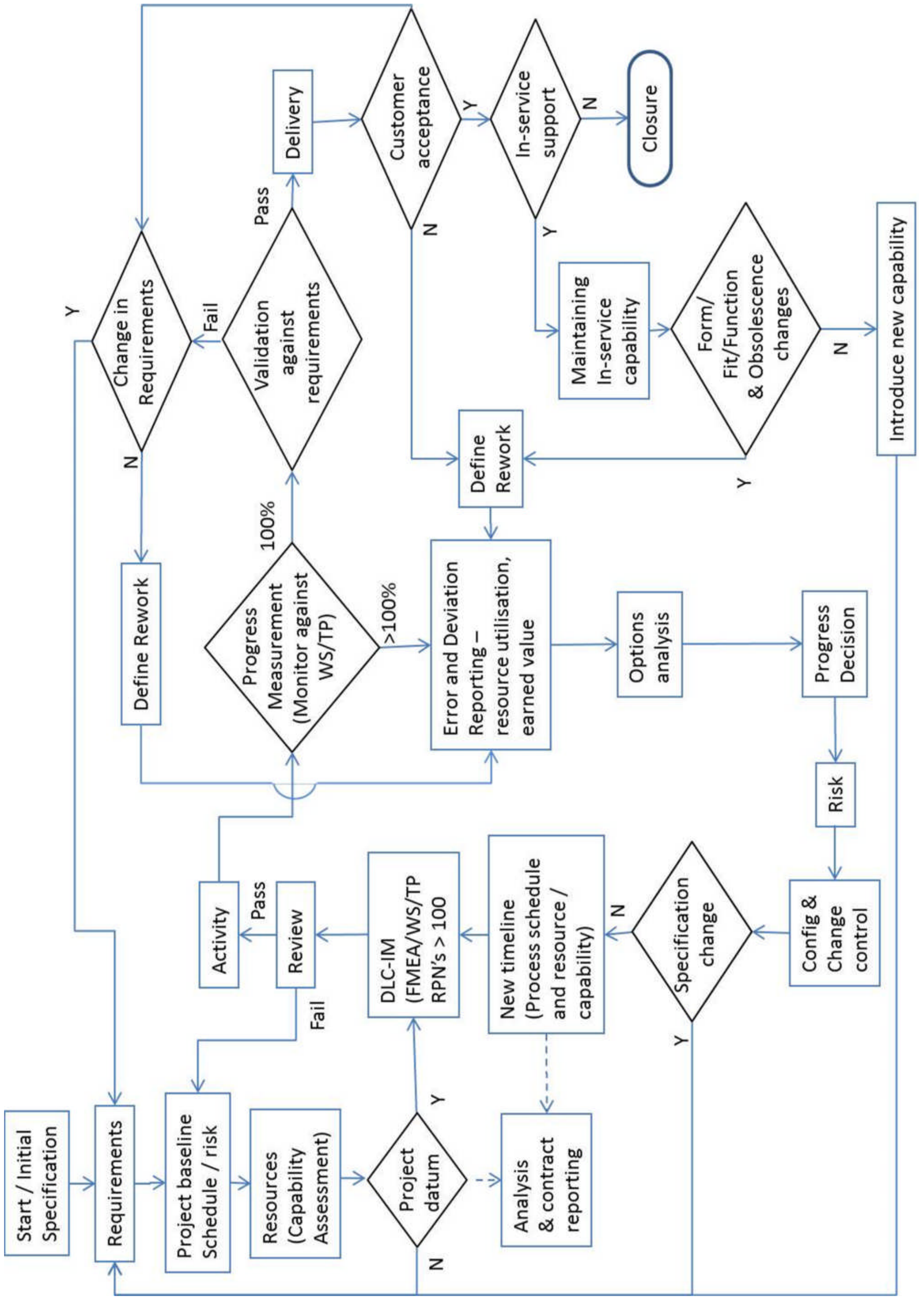

Figure 28: Integrated DLC-IM and project process mode

7.4 Development towards general theory

The assessment of the research activity in section 7.1 concluded that significant issues exist within project management. However, it was still possible to identify topics on which focused research could be conducted.

This section summarised this discussion and considers how further progress might be made.

The major issue is the lack of community paradigm (Kuhn, 1996). The literature review in chapter two and methodology investigation in chapter three identified design science as a candidate for the community paradigm. It was not practical to investigate this approach in detail within the scope of this research. It is discussed in general terms below as a topic for further work.

The research issue of project performance highlighted the need for this function within the project management 'tool box'. The focused research model (DLC-IM, figure 24) illustrated an approach to providing a practical process for industry. The case studies illustrated its potential application. Further work is needed in an industrial application to support development of the tool.

Alternative approaches to investigation such as: "*identifying anomalies*" (Carlile and Christiansen, 2005) and "*probematisation*" (Alvesson and Sandberg, 2011), were discussed in chapters two and four. These models propose challenging the underlying arguments and theoretical foundations of the research subject, rather than identifying research topics by 'gap spotting'. This is necessary in a field that is challenging because the underlying theory cannot be readily identified. By adopting Alvesson and Sandberg, (2011) it was possible to challenge the fundamental issues. This aligns with the argument made by Hällgren (2012).

Developing the previous discussion, it would appear that a fundamental study of the underlying aspects of project management is needed. The multiple 'schools of thought' illustrate the problem and their diversity supports the pre-paradigm view (Bredillet 2010c, page 6). One potential approach might be to examine the theoretical foundations of the various schools and test for commonality from which a community paradigm might be constructed.

In the more general sense, the initial discussion in chapter two identified 'Design Science' as a possible foundation, and suggested that there was an argument within the management sciences to support this (Tranfield 2002b, Söderlund 2011). Further to this, viewing design science from the applied disciplines perspective, the typical industrial sectors to which project management is applied all showed evidence of a design science based school of thought. The conclusion is that design science is worth further investigation, which is discussed in the next section.

The further development of the research focus and the 'deviation lifecycle' model and its industrial application (DLC-IM) align with the potential development of theory and the potential of a design science based community paradigm, and challenge some, but not all, of the typical project management toolset (figures 13 and 28). In this respect the research aligns with Davis (1971).

7.5 Contribution to knowledge

Contribution to knowledge is in the context of the general project management body of knowledge. The bodies of knowledge offered by the various professional organisations offer practitioner advice but don't support underlying theory (see section 2.7). Challenging the body of knowledge and exploring underlying theory provided the basis for research.

Morris (2000) defined knowledge as the interpretation of information in order to contribute to the development of theory. Discussion of the thesis must examine if a contribution has been made.

By investigating the scientific foundation and underlying theory the main issue identified was the lack of community paradigm. Locating project management on the research spectrum provided a basis to work from and also recognised the potential relation to design science. Identification of the lack of community paradigm led to the conclusion that more research in this area was necessary – this provides the context for the high level contribution. Design science offers a candidate for the development of a community paradigm and is considered for further work.

The high level contribution to knowledge was the need to develop the community paradigm and the potential for design science to provide the foundation. This was discussed further in sections 6.2.1 and 7.3.

The subsequent investigation identified numerous operational issues. The development of the research focus took the view that if project management is to be recognised as a discipline then it is necessary to treat it independently of specific industrial application, although respecting the need for industrial knowledge to support any specific project.

The 'information' gathered around these topics was interpreted to develop these views on the potential development of the project management discipline. This led to the identification of 'deviation' as a lifecycle function of the project – including antecedents (Liu et al., 2010) and early stage analysis prior to Hällgren (2009).

The development of the research focus examined the topics identified in the literature review and concluded that 'prediction' was a missing function in the project management toolset.

This was developed to propose that deviation could be considered a lifecycle function within the project management toolset, and proposed the contribution of the deviation lifecycle. Literature review did not identify any existing references to this concept. The industrial investigation illustrated its potential application, proposing the contribution of extending FMEA to examine ‘performance’ as opposed to the traditional applications to ‘product’ and ‘process’. The research model indicated this could be applied.

Using qualitative methods led to constructed knowledge, as discussed in section 5.2.1. and Table 5.

Building on the discussion identifying drivers for future project management development (Broader conceptualisation, Value (Winter et al., 2006), Bannerman (2013) states: “*Capabilities are organisational resources that have potential to generate value for a firm*.”

Detail contribution to knowledge can be summarised as recognising the need for a performance prediction function which is presented in the Deviation Lifecycle model and the extension of FMEA as a performance test.

7.6 Further work

The fundamental theoretical problem for project management is the lack of community paradigm. Without this ‘normal science’ in the sense of Kuhn (1996) cannot progress. This was recognised by Bredillet (2010c), and more generally in terms of the multiple schools of thought being presented by various authors.

Developing the ‘Schools of Thought’ (table 3), a central area of future work might be to investigate the underlying theory and research position of the various schools of thought and examine the potential common ground, from which contribution to the basis of a community paradigm might emerge.

Further work to establish the location of project management from scientific first principles might offer progress towards a potential community paradigm. The investigation conducted here suggested ‘Design Science’ (Simon, 1996) as a candidate. Further work to understand the current ‘state of the art’ of design science and how it might provide the basis of a community paradigm is needed.

The research focus identified the lack of ‘prediction’ as a project management function. As project management is generally concerned with the definition of activities that are yet to happen (i.e. planned), then prediction of their general behaviours is significant.

Focusing on performance prediction, the research model and industrial investigation indicated potential benefit. Further work is needed to develop the role and position it within the project management structure. Identification or development of further techniques to minimise the initial work and maximize the benefit is required.

The argument for project management to be fully recognised and a discipline must require the underlying basis to be independent of any specific industrial application. Further work will be needed to examine the application of the functional model within different industries and test its general role. Whilst it is recognised that industry specific knowledge is relevant to any particular application, the underlying methodology of a discipline must be generally applicable.

One option might be to revise the research model to test the project task for performance issues from a capability perspective, based on Bannerman (2013). This test might highlight strengths and weaknesses of the project plan at an earlier stage.

Bannerman (2013) discussed a ‘capability’ theory based on identification of positive and negative processes that contribute to overall project performance. This could provide a more rigorous process model to identify the functions discussed in chapter four (figure 12) and to apply the DLC-IM analysis to by using topics that contribute to capability rather than ‘success / failure’ criteria as the basis of the analysis.

7.7 Summary

Overall investigation of project management identified fundamental issues with the lack of community paradigm. This necessitated developing the research issue by analysing, and challenging, the underlying assumptions of the subject.

By examining the fundamental basis of the subject the lack of performance prediction emerged as a research issue.

Development of the DLC-IM research model allowed the research issue to be examined by testing the research question.

The case studies illustrated potential application and suggested further work.

As a potential process model (figures 13 and 27) illustrated the integration of the research model into the broader project management process and showed that the research challenged some, but not all, of the underlying assumptions, following Davis (1971) and Alvesson and Sandberg (2011).

Consequently the focused research suggests potential to contribute to the broader development of project management and is consistent with the higher level discussion on the development of the community paradigm.

The overall development of the community paradigm remains the fundamental issue preventing ‘normal science’ (Kuhn, 1996) to be applied (Bredillet 2010c, page 6).

The proposal is that design science is a reasonable candidate, supported academically (Tranfield, 2002b; Söderlund, 2011) and industrially (Table 69) and should be the underlying focus of further work.

Based on the literature review and the development of the research focus, the discussion can be summarised as:

- Projects and their management are being applied to a broad and increasing spectrum of business and industrial sectors in open systems that are defined by objectives (specific and / or service provision), bounded by delivery constraints, and applied over the product lifecycle utilising a project lifecycle model.
- Project management is located as a sub-field of management science. There is strong suggestion that it should be founded in design science. Its application provides a globally integrated functional process model

tailored to deliver the requirements of a specific project to an optimised, value added solution, consistent with stakeholder's strategic aims.

- Performance is an emergent property of the project organisations capability, resulting from integration of the detailed behaviours of planned and un-planned activities, product configuration, change management and contingency applicable as the project evolves.
- Project managers are the leaders and implementers responsible for the marketing, decision making and governance within a project organisation to ensure the required performance to deliver value and success to stakeholders is achieved.

Integrating these dimensions into a coherent activity to achieve business benefit requires continuous proactive involvement and commitment by all members of the project team, it is more than 'plan the work and work the plan'. It requires awareness of the global issues and the detail, recognition of how to maximise the value of the resources and willingness to change and adapt whilst minimising adverse effects. This needs a continuous performance monitoring process. Within this overall activity, prediction of potential issues may be useful in reducing the potential for the tasks to deviate, and therefore, when integrated across the project network, provide some improvement in project performance.

REFERENCES

AAAS (American Association for the Advancement of Science). 1989
Science for All Americans: A project 2061 Report on Literacy Goals in Science, Mathematics, and Technology.
Washington, DC: AAAS

Achterkamp, M. C., Vos, J. F. J. (2008)
Investigating the use of the stakeholder notion in project management literature, a meta-analysis
International Journal of Project Management, Vol. 26, pp. 749–757

Adner, R., Pólos, L., Ryall, M., Sorenson, O. (2009)
Introduction to special topic forum: the case for formal theory
Academy of Management Review, Vol. 34, No. 2, pp. 201–208.

Ahlemann, F., El Arbi, F., Kaiser, M. G., Heck, A. (2013)
A process framework for theoretically grounded prescriptive research in the project management field
International Journal of Project Management, Vol. 31, pp. 43–56

Ainamo, A., Artto, K., Levitt, R. E., Orr, R. J., Scott, W. R., Tainio, R. (2010)
EDITORIAL: Global projects: Strategic perspectives
Scandinavian Journal of Management, Vol. 26, pp. 343—351

Aladwani, A. M. (2002)
An Integrated Performance Model of Information Systems Projects
Journal of Management Information Systems Vol. 19. No. l. pp. 185-210.

Albores-Barajas, P. A. (2006)
Understanding The Effects Of E-Business On Business Processes: A Simulation Approach
PhD Thesis, University of Strathclyde, Glasgow UK
http://ethos.bl.uk/Home.do

Altfeld, H-H. (2010)
Commercial Aircraft Projects
Ashgate, Farnham

Alvesson, M., Sandberg, J. (2011)
Generating Research Questions Through Problematization
Academy of Management Review Vol. 36, No. 2, pp. 247 – 271

Anagnostopoulos, K. P. (2004)
Project Management: Epistemological Issues and Standardization of Knowledge
Operational Research. An International Journal. Vol. 4, No. 3, pp 249-260

Anbari, F. T., Bredillet, C. N., Turner, J. R. (2008)
Perspectives on Research in Project Management.
Academy of Management Proceedings; 1 pp. 1-6

Anderson, D. K., Merna, T. (2003)
Project Management Strategy—project management represented as a process based set of management domains and the consequences for project management strategy
International Journal of Project Management, Vol. 21, pp. 387–393

Ansoff, H. I. (1975)
Managing Strategic Surprise by Response to Weak Signals
California Management Review, Vol. 18, No. 2, pp. 21-33

APMBoK
http://www.apm.org.uk/BOK6

Arbnor, I., Bjerke, B. (1997)
Methodology for Creating Business Knowledge
Thousand Oaks: Sage (2nd Edition)

Arnäs, P. O., Holmström, J., Kalantari, J. (2013)
In-transit services and hybrid shipment control: The use of smart goods in transportation networks
Transportation Research Part C, Vol. 36, pp. 231–244

Artto, K., Wikström, K. (2005)
What is project business?
International Journal of Project Management, Vol. 23, pp. 343–353

Artto, K., Wikström, K., Hellström, M., Kujala, J. (2008)
Impact of services on project business
International Journal of Project Management, Vol. 26, pp. 497–508

Atkinson, R., Crawford, L., Ward, S. (2006)
Fundamental uncertainties in projects and the scope of project management
International Journal of Project Management, Vol. 24, pp. 687–698

Avots, I. (1969)
Why does Project Management Fail?
California Management Review, Vol. XII, No. 1

Baccarini, D. (1996)
The concept of project complexity a review
International Journal of Project Management, Vol. 14, No. 4, pp. 201-204

Bannerman, P.L. (2013)
Barriers to Project Performance
46th Hawaii International Conference on System Sciences

Barnes, D. (2001)
Research Methods for the empirical investigation of the process of formation of operations strategy.
International Journal of Operations & Production Management, Vol. 21, pp. 1076-1095

Barnes, J. (2000)
Aristotle – A Very Short Introduction.
Oxford University Press

Barrett, P., Barrett, L. (2006)
The 4Cs model of exemplary construction projects
Engineering, Construction and Architectural Management, Vol. 13 Issue: 2, pp.201 - 215

Berkun, S. (2008)
Making Things Happen
O'Reilly

Besner, C., Hobbs, B. (2008)
Project Management Practice, Generic or Contextual: A Reality Check
Project Management Journal, Vol. 39, No. 1, pp. 16–33

Besner, C., Hobbs, B. (2012)
An Empirical Identification of Project Management Toolsets and a Comparison Among Project Types
Project Management Journal, Vol. 43, No. 5, pp. 24–46

Betts M., Lansley P. (1995)
International journal of project management: a review of the first ten years.
International Journal Project Management; Vol. 13 No. 4, pp. 207-218.

Bevan, H., Glenn, R., Bate, P., Maher, L., Wells, J. (2007)
Using a Design Approach to Assist Large-Scale Organizational Change
The Journal of Applied Behavioral Science, Vol. 43, Iss. 1, pp. 135-152

Black, T. R. (1999)
Doing Quantitative Research in the Social Sciences
Sage Publications

Blaikie, N. (2000)
Designing Social Research
Cambridge: Polity.

Bloebaum, C. L., McGowan, A-M, R. (2012)
The Design of Large-Scale Complex Engineered Systems: Present Challenges and Future Promise
12th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference and 14th AIAA/ISSM, 17 - 19 September 2012, Indianapolis, Indiana

Blyth, K., Lewis, J., Kaka, A. (2004)
Predicting project and activity duration for buildings in the UK
Journal of Construction Research, Vol. 5, No. 2, pp. 329-347

Boddy, D., Macbeth, D. (2000)
Prescriptions for managing change: a survey of their effects in projects to implement collaborative working between organisations
International Journal of Project Management, Vol. 18, pp. 297-306

Bodenbenner, P., Feuerriegel, S., Neumann, D. (2013)
Design Science in Practice: Designing an Electricity Demand Response System
In: J. vom Brocke et al. (Eds.): DESRIST 2013, LNCS 7939, pp. 293–307,

Börner, K., Boyack, K. W., Milojević, S., Morris, S. (2012)
An introduction to modelling science: Basic model types, key definitions, and a general framework for comparison of process models.
Chapter 1 in "Models of Scientific dynamics – Encounters between complexity theory and information sciences" Springer book in the Understanding Complex Systems series, Editors: Scharnhorst, A. Börner, K. van den Besselar, P.

Braun, T., Ferreira, A. I., Sydow, J. (2013)
Citizenship behavior and effectiveness in temporary organizations
International Journal of Project Management, Vol. 31, pp. 862–876

Bredillet, C. N. (2006a)
The Link Research—Practice: A Matter of "Ingenium" (Part 1)
Project Management Journal, September 2006

Bredillet, C. N. (2006b)
The Link Research—Practice: A Matter of "Ingenium" (Part 2)
Project Management Journal, December 2006

Bredillet, C. N. (2007a)
The Link Research—Practice: A Matter of "Ingenium" (Part 3)
Project Management Journal, March 2007

Bredillet, C. N. (2007b)
Exploring Research in Project Management – Nine Schools of Project Management Research (Part 1)
Project Management Journal, Vol. 38, No. 2, pp. 3-4

Bredillet, C. N. (2007c)
Exploring Research in Project Management – Nine Schools of Project Management Research (Part 2)
Project Management Journal, Vol. 38, No. 3, pp. 3-5

Bredillet, C. N. (2007d)
Exploring Research in Project Management – Nine Schools of Project Management Research (Part 3)
Project Management Journal, Vol. 38, No. 4, pp. 2-4

Bredillet, C. N. (2008a)
Exploring Research in Project Management – Nine Schools of Project Management Research (Part 4)
Project Management Journal, Vol. 39, No. 1, pp. 2-6

Bredillet, C. N. (2008b)
Exploring Research in Project Management – Nine Schools of Project Management Research (Part 5)
Project Management Journal, Vol. 39, No. 2, pp. 2-4

Bredillet, C. N. (2008c)
Exploring Research in Project Management – Nine Schools of Project Management Research (Part 6)
Project Management Journal, Vol. 39, No. 3, pp. 2-5

Bredillet, C. N. (2008d)
Mapping the Dynamics of the Project Management field: Project Management in Action (Part 1)
Project Management Journal, Vol. 39, No. 4, pp. 2-4

Bredillet, C. N. (2009a)
Mapping the Dynamics of the Project Management field: Project Management in Action (Part 2)
Project Management Journal, Vol. 40, No. 2, pp. 2-6

Bredillet, C. N. (2009b)
Mapping the Dynamics of the Project Management field: Project Management in Action (Part 3)
Project Management Journal, Vol. 40, No. 3, pp. 2-5

Bredillet, C. N. (2009c)
Mapping the Dynamics of the Project Management field: Project Management in Action (Part 4)
Project Management Journal, Vol. 40, No. 4, pp. 2-5

Bredillet, C. N. (2010a)
Mapping the Dynamics of the Project Management field: Project Management in Action (Part 5)
Project Management Journal, Vol. 41, No. 1, pp. 2-4

Bredillet, C. N. (2010b)
Mapping the Dynamics of the Project Management field: Project Management in Action (Part 6)
Project Management Journal, Vol. 41, No. 2, pp. 2-4

Bredillet, C. N. (2010c)
Blowing Hot and Cold on Project Management
Project Management Journal, Vol. 41, No. 3, pp. 4-20

Browning, T. R., Fricke, E., Negele, H. (2006)
Key Concepts in Modeling Product Development Processes*
Systems Engineering, Vol. 9, No. 2, pp. 104-128

Bruni, M. E., Guerriero, F., Pinto, E. (2009)
Evaluating project completion time in project networks with discrete random activity durations
Computers & Operations Research Vol. 36, pp. 2716-2722

Bryman, A., Bell, E. (2007, 2nd Edition)
Business Research Methods
Oxford University Press

Burke, R. (2007)
Project Management Techniques
www.burkepublishing.com

Busby, J. S., Hughes, E. J. (2004)
Projects, pathogens and incubation periods
International Journal of Project Management, Vol. 22, pp.425–434

Butterfield, L. D., Borgen, W. A., Amundson, N. E., Maglio, A-S. T. (2005)
Fifty years of the critical incident technique: 1954–2004 and beyond
Qualitative Research, Vol. 5, pp. 475-497

Campbell, D.T., Stanley, J.C. (1963)
Experimental and Quasi-experimental Design for Research.
Boston: Hougthon Mifflin Press.

Carlile, P. R., Christensen, C. M. (2005)
The cycles of theory building in management research (Version 6.0.).
Retrieved December 3rd, 2012, from:
http://www.innosight.com/documents/Theory%20Building.pdf

Cheung, S. O., Yiu, T. W., Lam, M. C. (2013)
Interweaving Trust and Communication with Project Performance
Journal of Construction Engineering and Management, August 2013, pp. 941-950

Cicmil, S., Williams, T., Thomas, J., Hodgson, D. (2006)
Rethinking Project Management: Researching the actuality of projects
International Journal of Project Management, Vol. 24, pp. 675–686

Cioffi, D. F. (2006)
Designing project management: A scientific notation and an improved formalism for earned value calculations
International Journal of Project Management, Vol. 24, pp. 136–144

Clarke, A. (1999)
A practical use of key success factors to improve the effectiveness of project management
International Journal of Project Management, Vol. 17, No. 3, pp. 139-145

Coley, F. J. (2008)
Whole System Design
PhD Thesis, Cranfield University
http://ethos.bl.uk/Home.do

Cooke-Davies, T. (2002)
The "real" success factors on projects
International Journal or Project Management, Vol. 20, pp.185-190

Cooke-Davies, T. J. (2004).
Consistently Doing the Right Projects and Doing Them Right – What Metrics Do You Need?
http://cms.3rdgen.info/3rdgen_sites/107/resource/orcooked.pdf

Cooke-Davies, T. J., Arzymanow, A. (2003)
The maturity of project management in different industries: An investigation into variations between project management models
International Journal of Project Management, Vol. 21, pp. 471–478

Cooke-Davies, T., Cicmil, S., Crawford, L., Richardson, K. (2007)
We're Not in Kansas Anymore, Toto: Mapping The Strange Landscape of Complexity Theory, And Its Relationship To Project Management
Project Management Journal Vol. 38, No. 2, pp.50-61

Coulon, T., Barki, H., Paré, G. (2013)
Conceptualizing Unexpected Events in IT Projects
Thirty Fourth International Conference on Information Systems, Milan 2013

Crawford, L., Morris, P., Thomas, J., Winter, M. (2006b)
Practitioner development: From trained technicians to reflective practitioners
International Journal of Project Management, Vol. 24, pp. 722–733

Crawford, L., Pollack, J., England, D. (2006a)
Uncovering the trends in project management: Journal emphases over the last 10 years
International Journal of Project Management, Vol. 24, pp. 175–184

Davis, M. S. (1971)
That's interesting; Towards a phenomenology of sociology and a sociology of phenomenology
Phil. Soc. Sci. Vol. 1, pp. 309-344

Denscombe, M. (2002)
The Good Research Guide: for small-scale social research projects.
Buckingham: Open University Press.

Denyer, D., Tranfield, D., van Aken, J. E. (2008)
Developing Design Propositions through Research Synthesis
Organization Studies 29(03), pp. 393–413

Denzin, N. K., Lincoln, Y. S. (2003)
Handbook of Qualitative Research (2nd edition)
Sage Publications

Dew, J. (2006)
TRIZ: A Creative Breeze for Quality Professionals
Quality Progress, Volume 39, Issue 1, pp. 44-51

Derelöv, M., Detterfelt, J., Björkman, M., Mandenius, C-F. (2008)
Engineering Design Methodology for Bio-Mechatronic Products
Biotechnol. Prog.,Vol 24, pp. 232-244

Dougherty, D., Dunne, D. D. (2012)
Digital Science and Knowledge Boundaries in Complex Innovation.
Organization Science Vol. 23 Issue 5, pp.1467-1484.
http://dx.doi.org/10.1287/orsc.1110.0700

Dvir, D., Lechler, T. (2004)
Plans are nothing, changing plans is everything: the impact of changes on project success
Research Policy Vol. 33, pp. 1–15

Easterby-Smith, M., Thorpe, R., and Lowe, A. (1991)
Management Research: An Introduction
London: Sage

Easterby-Smith, M., Thorpe, R., Jackson, P. R. (2008)
Management Research (3rd edition)
London, Sage

Eden, C., Williams, T., Ackermann, F., (2005)
Analysing project cost overruns: comparing the ‘‘measured mile’’ analysis and system dynamics modelling
International Journal of Project Management, Vol. 23, pp. 135–139

Eisenhardt, K. M. (1989)
Building Theories from Case Study Research
Academy of Management Review, Vol. 14, No. 4, pp. 532 – 550

Ekstedt, E., Wirdenius, H. (1995)
Renewal projects: Sender target and receiver competence in ABB "T50" and Skanska "3T"
Scandinavian Journal of Management, Vol. 11, Issue 4, pp. 409-421

Elg, M., Broryd, K. P., Kollberg, B. (2013)
Performance measurement to drive improvements in healthcare practice
International Journal of Operations & Production Management, Vol. 33 Issue 11/12 pp. 1623 - 1651

Engwall, M. (1998).
The ambiguous project concept(s)
In: Lundin, R.A. and Midler, C. (eds),
Projects as Arenas for Renewal and Learning Processes.
Boston, MA: Kluwer Academic Publishers, pp. 25–36.

Evaristo, R., van Fenema, P. C. (1999),
A typology of project management: emergence and evolution of new forms
International Journal of Project Management, Vol. 17, No. 5, pp. 275-281

Eve, A. (2007)
Development of project management systems
Industrial and Commercial Training, Vol. 39, No. 2, pp. 85-90

Eveleens, J. L., Verhoef, C. (2010)
The Rise and Fall of the Chaos Report Figures
IEEE SOFTWARE Published by the IEEE Computer Society

Fan I-S. (1988)
Intelligent flexible manufacturing system control
PhD Thesis, Cranfield Institute of Technology, Cranfield University
http://ethos.bl.uk/Home.do

Farrell, R., Hooker, C. (2012)
The Simon-Kroes model of technical artifacts and the distinction between science and design
Design Studies, Vol. 33, pp. 480-495

Flanagan, J. C. (1954)
The Critical Incident Technique
Psychological Bulletin, Vol. 51, No. 4, pp. 327-358

Floricel, S., Bonneau, C., Aubry, M., Sergi, V. (2014)
Extending project management research: Insights from social theories
International Journal of Project Management, Vol. 32, pp. 1091–1107

Flyvbjerg, B. (2006)
From Nobel Prize to Project Management: Getting Risks Right
Project Management Institute, Vol. 37, No. 3, pp. 5-15,

Flyvbjerg, B. (2014)
What You Should Know About Megaprojects and Why: An Overview
Project Management Journal, Vol. 45, No. 2, pp. 6–19

Flyvbjerg, B., Bruzelius, N., Rothengatter, W. (2003)
Megaprojects and risk: an anatomy of ambition
Cambridge University Press

Ford, R., Randolph, A. (1992)
Cross-functional structures: a review and integration of matrix organization and project management
Journal of Management, 18, pp. 267–294

Foresight (2013)
The Future of Manufacturing: A new era of opportunity and challenge for the UK.
London: The Government Office for Science
Downloaded (7th Oct 2014):
https://www.gov.uk/government/collections/future-of-manufacturing

Fortune, J., White, D. (2006)
Framing of project critical success factors by a systems model
International Journal of Project Management, Vol. 24, pp. 53–65

Gaddis, P. O. (1959)
The Project Manager
Harvard Business Review, May – June, pp. 89-97

Galle and Kroes (2014)
Science and design: Identical twins?
Design Studies Vol. 35, pp. 201-231

Galway, J. (2004)
Quantitative Risk Analysis for Project Management
RAND Corporation, Santa Monica

Garel, G. (2013)
A history of project management models: From pre-models to the standard models
International Journal of Project Management, Vol. 31 pp. 663–669

Gauch, H. G. (2003)
Scientific Method in Practice (1st Edition)
Cambridge University Press

Gauthier, J-B., and Ika, L. A. (2012)
Foundations of Project Management Research: An Explicit and Six-Facet Ontological Framework
Project Management Journal, Vol. 43, No. 5, pp. 5-23

Geraldi, J. G., Turner, J. R., Maylor, H., Söderholm. A., Hobday, M., Brady, T. (2008)
Innovation in project management: Voices of researchers
International Journal of Project Management, Vol. 26, pp. 586 – 589

Ghazarian, A. (2013)
Requirements engineering for business information systems: A dimension-oriented approach
WSEAS Transactions on Business and Economics, Vol. 10, Issue 3, pp. 229-242

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., Trow, M. (1994)
The New Production of Knowledge: The Dynamics of Science and Research in contemporary societies
London; Sage

Glaser, B., Straus, A. (1967)
The Discovery of Grounded Theory: Strategies of Qualitative Research.
London: Wiedenfeld and Nicholson

Glass, R. L. (2005)
IT Failure Rates-70% or 10-15%?
IEEE SOFTWARE, IEEE Computer Society

Glass, R. L. (2006)
The Standish Report: Does it Really Describe a Software Crisis?
Communication of the ACM, Vol. 49, No. 8

Gonzalez, F.J.A., Castro, C.B., Bueno, J.C.C. and Gonzalez, J.L.G. (2001)
'Dominant approaches in the field of management'
The International Journal of Organizational Analysis, Vol. 9, No. 4, pp.327–353.

Gregor, S. (2009)
Building Theory in the Sciences of the Artificial
DESRIST'09, May 7-8, 2009, Malvern, PA, USA.

Gregor, S., Hevner, A. R., (2013)
Positioning and Presenting Design Science Research for Maximum Impact
MIS Quarterly, Vol. 37, No. 2, pp. 337-355

Grix, J. (2002)
Introducing Students to the Generic Terminology of Social Research
Politics, Vol. 22, No. 3, pp. 175-186

Hällgren, M. (2009)
Mechanisms of deviations: observations of projects in practice
International Journal of Managing Projects in Business, Vol. 2, No. 4, pp. 611-625

Hällgren, M. (2012)
The construction of research questions in project management
International Journal of Project Management, Vol. 30, pp. 804–816

Hällgren, M., Maaninen-Olsson, E. (2009)
Deviations and the breakdown of project management principles
International Journal of Managing Projects in Business, Vol. 2 No. 1, pp. 53-69

Hambrick, D. C., Chen, M-J. (2008)
New Academic Fields as Admittance Seeking Social Movements: The Case Of Strategic Management
Academy of Management Review, Vol. 33, No. 1, pp. 32–54.

Hameri, A-P., Puittinen, M., Syrjälahti, M. (2002)
Organizational emergence in networked collaboration
International Journal of Communication Systems; Vol. 15, pp. 607–619

Hanif, T. (2011)
A new approach to Project Management based on a combination of Predictive and adaptive thinking
PhD Thesis, Kingston University
http://ethos.bl.uk/Home.do

Hanisch, B., Wald A. (2011)
A Project Management Research Framework Integrating Multiple Theoretical Perspectives and Influencing Factors
Project Management Journal, Vol. 42, No. 3, pp. 4–22

Hanisch, B., Wald A. (2012)
A Bibliometric View on the Use of Contingency Theory in Project Management Research
Project Management Journal, Vol. 43, No. 3, pp. 4–23

Haponava, T., Al-Jibouri, S. (2012)
Proposed System for Measuring Project Performance Using Process-Based Key Performance Indicators
Journal of Management in Engineering (American Society of Civil Engineers), April 2012, pp. 140-149

Hatchuel, A. (2001)
The Two Pillars of New Management Research
British Journal of Management, Vol. 12, Special Issue, S33-S39

Hatchuel, A. (2005)
Towards an epistemology of collective action: management research as a responsive and actionable discipline
European Management Review, 2, pp. 36–47

Hatchuel, A. (2009)
A foundationalist perspective for management research: a European trend and experience
Management Decision, Vol. 47 No. 9, pp. 1458-1475

Hellgren, B., Stjernberg, T. (1995)
Design and implementation in major investments – A project network approach
Scandinavian Journal of Management, Vol. 11, Iss. 4, pp. 377-394

Herroelen, W. (2005)
Project Scheduling – Theory and practice
Production and Operations Management, Vol. 14, No. 4, pp. 413–432

Herroelen, W., Leus, R. (2005)
Project scheduling under uncertainty: Survey and research potentials
European Journal of Operational Research 165, pp. 289–306

Hevner, A. R., March, S. T., Park, J., Ram. S. (2004)
Design Science in Information Systems Research
MIS Quarterly Vol. 28 No. 1, pp. 75-105

Hodgkinson, G. P., Rosseau, D. M. (2009)
Bridging the Rigour–Relevance Gap in Management Research: It's Already Happening!
Journal of Management Studies 46:3, pp. 534-546

Hodgkinson, G. P., Starkey, K. (2011)
Not Simply Returning to the Same Answer Over and Over Again: Reframing Relevance
British Journal of Management, Vol. 22, pp. 355–369

Hodgkinson, G. P., Starkey, K. (2012)
Extending the Foundations and Reach of Design Science: Further Reflections on the Role of Critical Realism
British Journal of Management, Vol. 23, pp. 605–610

Holopainen, M., Toivonen, M. (2012)
Weak signals – Ansoff today
Futures, 44,pp.198–205

Hughes, S. W., Tippett, D. D., Thomas, W. K.(2004)
Measuring Project Success in the Construction Industry
Engineering Management Journal Vol. 16 No. 3, pp. 31-37

Iivari, J. (2007)
A Paradigmatic Analysis of Information Systems As a Design Science
Scandinavian Journal of Information Systems: Vol. 19: Issue 2, Article 5.
Available at: http://aisel.aisnet.org/sjis/vol19/iss2/5

Jaafari, A. (2001)
Management of risks, uncertainties and opportunities on projects: time for a fundamental shift
International Journal of Project Management, Vol. 19, pp. 89-101

Jacobsson M., Söderholm, A. (2011)
Breaking out of the straitjacket of project research: in search of contribution
International Journal of Managing Projects in Business Vol. 4 No. 3, pp.378-388

Jamali, K., Hashmi, S.M. (2010)
Managing projects through the theory of inventive problem solving (TRIZ)
International Research Journal of Finance and Economics, Vol. 44, pp. 174-190

Jarratt, T. A. W., Eckert, C. M., Caldwell, N. H. M., Clarkson, P. J. (2011)
Engineering change; an overview and perspective on the literature.
Res Eng Design, Vol. 22, pp.103–124

Jørgensen, M., Moløkken-Østvold, K. (2006)
How large are software cost overruns? A review of the 1994 CHAOS report
Information and Software Technology 48 (2006) pp. 297–301

Jørgensen, M. (1994)
Empirical studies of software maintenance
PhD thesis, University of Oslo, Department of Informatics
https://www.simula.no/research/se/publications/SE.3.Joergensen.1994

Johnson, S. B. (2013)
Technical and institutional factors in the emergence of project management
International Journal of Project Management, Vol. 31, pp. 670–681

Jugdev, K. (2004)
Through The Looking Glass: Examining Theory Development in Project Management with the Resource-Based View Lens
Project Management Journal, Vol. 35, No. 3, pp. 15-26

Jugdev, K. (2008)
Good theory: developing a foundation for project management
International Journal of Product Development, Vol. 6, No. 2, pp. 177-189

Kadefors, A. (1995)
Institutions in building projects: Implications for flexibility and change
Scandinavian Journal of Management, Vol. 11, Iss. 4 pp. 395-408

Kaplan, A. (1964)
The Conduct of Inquiry: Methodology for Behavioral Research
Scranton, PA: Chandler.

Kaplan, R. (1986)
The role for Empirical Research in Management Accounting
Accounting, Organizations and Society, 4, pp. 429-452.

Keil, M., Mähring, M. (2010)
Is Your Project Turning into a Black Hole?
California Management Review Vol. 53, No. 1, pp. 6-31

Klakegg, O. J., Williams, T., Walker, D., Andersen, B., Magnussen, O. M. (2010)
Early warning signs in complex projects
Project Management Institute, USA

Klimstra, P. D., Potts, J. (1988)
What We've Learned Managing R&D Projects
Research Technology Management, Vol. 31, Iss. 3, pg. 23 – 39

Kloppenborg, T.J., Opfer, W. A. (2000)
Forty years of project management research: Trends, interpretations, and predictions
In: PMI Research Conference. PMI, 2000. pp. 41–59.

Kloppenborg, T.J., and Opfer, W.A. (2002)
The current state of project management research: Trends, Interpretations, and Predictions.
Project Management Journal, Vol. 33, No. 2, pp. 5 – 18

Kolltveit, B. J., Karlsen, J. T., Grønhaug, K. (2007)
Perspectives on project management
International Journal of Project Management, Vol. 25, pp. 3–9

Komenda, M., Schwarz, D. (2013)
Visual Analytics in Environmental Research: A Survey on Challenges, Methods and Available Tools
In: J. Hřebíček et al. (Eds.): ISESS 2013, IFIP AICT 413, pp. 618–629

Koontz, H. (1980)
'The management theory jungle revisited'
Academy of Management Review, Vol. 5, No. 2, pp.175–187.

Koskela, L., Howell, G. (2001)
Reforming Project Management: The Role of Planning, Execution and Controlling
in: 9th International Group for Lean Construction Conference., August 2001, National University of Singapore.
Downloaded from: http://usir.salford.ac.uk/9384/

Koskela, L., Howell, G. (2002)
The Underlying Theory of Project Management is Obsolete.
Proceedings of the PMI Research Conference, 2002. pp. 293-302.
Downloaded from: http://usir.salford.ac.uk/9400/

Kozak-Holland, M. (2011)
The History of Project Management
Multi-Media Publications Inc.

Kreiner, K. (1995)
In search of relevance: Project management in drifting environments
Scandinavian Journal of Management, Vol. 11, Iss. 4, pp. 335-346

Kroes, P. (2002)
Design methodology and the nature of technical artefacts
Design Studies, Vol. 23, pp. 287–302

Kuhn, T. (1962, 1st Edition)
The Structure of Scientific Revolutions
Chicago: University of Chicago Press

Kuhn, T. S. (1996, 3rd Edition)
The Structure of Scientific Revolutions
The University of Chicago Press

Kutsch, E., Hall, M. (2005)
Intervening conditions on the management of project risk:
Dealing with uncertainty in information technology projects
International Journal of Project Management, Vol. 23, pp. 591–599

Kwak, Y. H., Anbari, F. T. (2009)
Analyzing project management research: Perspectives from
top management journals
International Journal of Project Management, Vol. 27, pp. 435–446

Lakatos, I. (1970)
Falsification and methodology of scientific research programmes.
In I. Lakatos & A. Musgrave (Eds.),
Criticism and the growth of knowledge, pp. 91–196
Cambridge, England: Cambridge University Press.

Lampel, J. (2001)
The core competencies of effective project execution: the challenge of diversity
International Journal of Project Management, Vol. 19, pp. 471–483

Lawrence, P., Scanlan, J. (2007)
Planning in the Dark: Why Major Engineering Projects Fail to Achieve Key Goals
Technology Analysis and Strategic Management Vol. 19, No. 4, pp. 509–525

Lee, C. C. (2007)
Developing an Appropriate Methodology for Matching Project Team's Knowledge with Client's Project Requirements in Refurbishment Projects
Glasgow Caledonian University
http://ethos.bl.uk/Home.do

Leedy, P. D., Ormrod, J. E. (2010, 9th Edition)
Practical Research – Planning and Design
Pearson, New York

Lenfle, S., Loch, C. (2010)
Lost Roots: How Project Management Came to Emphasize Control Over Flexibility and Novelty
California Management Review Vol. 53, No. 1, pp. 32-55

Leybourne, S. A. (2007)
The Changing Bias of Project Management Research: A Consideration of the Literatures and an Application of Extant Theory
Project Management Journal Vol. 38, No. 1, pp. 61-73

Liu, J. Y-C, Chen, H. H-G., Jiang, J. J., Klein, G. (2010)
Task completion competency and project management performance: The influence of control and user contribution
International Journal of Project Management 28 (2010) pp. 220–227

Liu, A. M. M., Walker, A. (1998)
Evaluation of project outcomes
Construction Management and Economics, Vol. 16, pp. 209-219

Littau,P., Jujagiri, N. J., Adlbrecht,G. (2010)
25 Years of Stakeholder Theory in Project Management Literature (1984–2009)
Project Management Journal, Vol. 41, No. 4, pp. 17–29

Locke, K., Golden-Biddle, K. (1997)
Constructing opportunities for contribution: structuring intertextual coherence and “probematizing” in organizational studies
Academy of Management Journal, Vol. 40, No. 5

Løwendahl, B. R. (1995)
Organizing the Lillehammer Olympic Winter games
Scandinavian Journal of Management, Vol. 11, Iss. 4, pp. 347-362

Ludwin, L. G. (2003)
The One-shot Deal: Temporary Organizations, UK Feature Film Units, and Learning Organization Theory
PhD Thesis, The Open University
http://ethos.bl.uk/Home.do

Lundin, R. A. (1995)
Editorial: Temporary organizations and project management
Scandinavian Journal of Management, Vol. 11, Iss. 4 pp. 315-318

Lundin, R. A., Söderholm, A. (1995)
A theory of the temporary organization
Scandinavian Journal of Management, Vol. 11, Iss. 4 pp. 437-455

Lyneis, J. M., Ford, D. N. (2007)
System dynamics applied to project management: a survey, assessment, and directions for future research
System Dynamics Review Vol. 23, No. 2/3, pp.157–189

Malan, A. (2006)
An Engineering Management Framework for Information Technology Projects in South Africa
D. Eng Thesis, University of Johannesburg, South Africa
https://ujdigispace.uj.ac.za/handle/10210/639

Mankins, J. C. (1995)
Technology Readiness Levels
Advanced Concepts Office, Office of Space Access and Technology, NASA
(Available on Google Scholar)

Marsh, E. R. (1975)
The Harmonogram of Karol Ademiecki
Academy of Management Journal, Vol. 18, No. 2, pp. 358-364

Martinez-Hernandez, V. (2003)
Understanding Value Creation: The Value Matrix and the Value Cube
University of Strathclyde, Glasgow UK
http://ethos.bl.uk/Home.do

Matta, N. F. Ashkena, R. N. (2003)
Why Good Projects Fail Anyway
Harvard Business Review (September)

Maylor, H., Brady, T., Cooke-Davies, T., Hodgson, D. (2006)
From projectification to programmification
International Journal of Project Management, Vol. 24, pp. 663–674

McKinsey Global Institute. (2013)
Infrastructure productivity: How to save $1 trillion a year
McKinsey and Company

Meredith, J. (1993)
Theory building through conceptual methods.
International Journal of Operations and Production Management, Vol. 13, No. 5: pp. 3-11

Midler, C. (1995)
"Projectification" of the firm: The Renault Case
Scandinavian Journal of Management, Vol. 11, Iss. 4 pp. 363-375

Mettler, T., Rohner, P. (2009)
Situational Maturity Models as Instrumental Artifacts for Organizational Design
4th International Conference on Design Science Research in Information Systems and Technology, DESRIST '09; Philadelphia, CA; United States; 7 May 2009 through 8 May 2009

Micaëlli, J.-P., Deniaud, S., Bonjour, É., Loise, D. (2013)
How to implement the abstract design paradigm: The case of requirements engineering
International Journal of Product Development, Vol 18, Issue 2, pp. 147-167

Mir, F. A., Pinnington, A. H. (2014)
Exploring the value of project management: Linking Project Management Performance and Project Success
International Journal of Project Management Vol. 32, pp. 202–217

Morris, P. W. G. (1997)
The management of projects
London: Thomas Telford

Morris, P. W. G. (2000)
Researching the unanswered questions of project management
Available online at:
http://www.indeco.co.uk/filestore/ResearchingtheUnansweredQuestionsofProjectManagement.pdf

Morris, P. W. G. (2002)
Science, objective knowledge and the theory of project management
Civil Engineering. Vol. 150, pp. 82-90

Morris, P. W. G. (2010)
Research and the future of project management
International Journal of Managing Projects in Business Vol. 3 No. 1, pp.139-146

Morris, P. W. G. (2013a)
Reconstructing Project Management
Willey-Blackwell

Morris, P. W. G. (2013b)
Reconstructing Project Management Reprised: A Knowledge Perspective
Project Management Journal, Vol. 44, No. 5, pp. 6 – 23

Morris, P. W. G., Crawford, L. Hodgson, D. Shepherd, M. M., Thomas, J. (2006)
Exploring the role of formal bodies of knowledge in defining a profession – The case of project management
International Journal of Project Management, Vol. 24, pp. 710–721

Morris, P. W. G., Hough, G. H. (1986)
Preconditions of success and failure in major projects
Templeton College, Oxford Centre for Management Studies

Morris, P. W. G., Hough, G. H. (1987)
The anatomy of major projects: a study of the reality of project management
Chichester: John Wiley, 1987.

Morris, P. W. G., Patel, M. B., Wearne, S. H. (2000)
Research into revising the APM project management body of knowledge
International Journal of Project Management, Vol. 18, pp. 155-164

Moser, C.A. and Kaltan, 0. (1971)
Survey methods in social investigation,
edn. Gower Aldershot.

MSP (2003)
OGC. Managing successful programmes. 2nd ed.
London: The Stationery Office

Mullaly, M. E., Thomas, J. (2007)
Relating to Project Management: Towards a Framework of Understanding
IRNOP VIII – Brighton, England (19-21 September 2007)

Munns, A. K., Bjeirmi, B. F. (1996)
The role of project management in achieving project success
International Journal of Project Management, Vol. 14, No. 2, pp. 81-87

Newton, I. (1704)
Opticks or, a treatise of the reflexions, refractions, inflexions and colours of light: also two treatises of the species and magnitude of curvilinear figures
Smith and Walford, Printers to the Royal Society (First edition)

Nicholas, J.M. (2001)
Project Management for Business and Technology
Prentice-Hall, Upper Saddle River, NJ.

Nicholas J.M., Steyn, H. (2008)
Project Management for Business, Engineering and Technology
Butterworth-Heinemann / Elsevier, Oxford, UK (3rd edition)

Niehaves, B. (2007)
On Epistemological Pluralism in Design Science
Scandinavian Journal of Information Systems, Vol. 19, Iss. 2, pp. 93-104

Nikander, I. O. (2002)
Early Warnings – A phenomena in project management
PhD Thesis, Helsinki University of Technology
Department of Industrial Engineering and Management
FIN-02015 TKK, Espoo, Finland
https://aaltodoc.aalto.fi/handle/123456789/2170

Nikander, I. O., Eloranta, E. (1997)
Preliminary signals and early warnings in industrial investment projects
International Journal of Project Management, Vol. 15, No. 6, pp. 371-376,

Nikander, I. O., Eloranta, E. (2001)
Project management by early warnings
International Journal of Project Management, Vol. 19, pp. 385-399

Ning, A., Hou, H., Hua, Q., Yu, B., Hao, K. (2005)
Requirements Engineering Processes Improvement: A Systematic View
Lecture Notes in Computer Science, Vol. 3840/2005, pp. 151-163

Packendorff, J. (1995)
Inquiring into the temporary organization: new directions for project management research
Scandinavian Journal of Management, Vol. 11, Iss.4, pp. 319– 334

Packendorff, J. (2002)
The temporary society and its enemies: Projects from an individual perspective
In: Sahlin-Andersson, K. and Söderholm, A. (eds.)
Beyond Project Management: New perspectives on the Temporary-Permanent Dilemma. pp. 39-58. Malmö: Liber.

Pandza, K., Thorpe, R. (2010)
Management as Design, but What Kind of Design? An Appraisal of the Design Science Analogy for Management
British Journal of Management, Vol. 21, pp. 171–186

Parsons, V. S. (2006)
Project Performance: How to Assess the Early Stages
Engineering Management Journal Vol. 18 No. 4, pp. 11-15

Partington, D. (1997)
Management processes in projects of organizational change: case studies from four industries
PhD Thesis, Cranfield University
http://ethos.bl.uk/Home.do

Peippo-Lavikka, P., Walker, D., Artto, K., Gemunden, H., Aaltonen, P. (2011)
Towards a project theory: Theoretical contents of project management in 9 industry sectors',
in Alfonso Gambardella and Maurizio Zollo (ed.) 11th EURAM Conference: Management Culture in the 21st Century, Tallinn, Estonia, 1-4 June 2011, pp. 1-40.

Pereira, R., Mira Da Silva, M. (2012)
Designing a new integrated IT Governance and IT Management framework based on both scientific and practitioner viewpoint (Review)
International Journal of Enterprise Information Systems, Vol 8, Iss. 4, pp. 1-43

Pinto, J. K. (2002)
Project Management 2002
Research ·Technology Management, March – April 2002

Pinto, J. K. (2014)
Project management, governance, and the normalization of deviance
International Journal of Project Management, Iss. 32, pp.376–387

Pitelis, C. N. (2014)
Rejuvenating 'Old Europe': Towards a strategy for reindustrialisation and sustainable competitiveness
Contributions to Political Economy, Iss. 33, pp. 69-98

Pollack, J. (2007)
The changing paradigms of project management
International Journal of Project Management, Vol. 25, pp. 266–274

PMBoK
http://www.pmi.org/PMBOK-Guide-and-Standards.aspx

Popper, K. (1959)
The Logic of Scientific Discovery
New York: Basic Books

Popper, K. (2002)
The Logic of Scientific Discovery
London and New York: Routledge.

Price, M., Raghunathan, S., Curran, R. (2006)
An integrated systems engineering approach to aircraft design
Progress in Aerospace Sciences Vol. 42, pp. 331–376

PRINCE2 (2005)
OGC. Managing successful projects with PRINCE2.
London: The Stationery Office

Reich, B. H., Liu, L,. Sauer, C., Bannerman, P., Cicmil, S., Cooke-Davies, T., Gemino, A., Hobbs, B., Maylor, H., Messikomer, C., Pasian, B., Semeniuk, M., Thomas, J. (2013)
Editorial: Developing better theory about project organizations
International Journal of Project Management, Vol. 31, pp. 938–942

Rico, D. F. (2010)
Lean and Agile Project Management: For Large Programs and Projects
In: P. Abrahamsson and N. Oza (Eds.): LESS 2010, LNBIP 65, pp. 37–43,

Riversimple: (http://www.riversimple.com) and
http://www.youtube.com/watch?v=TAVp8op_im8
The LIFECar project:
http://www.riversimple.com/Content.aspx?key=b13e5997-f983-4e8d-ae7a-d5cdf0cfcb3d&mode=

Roberts E. B. (1964)
The Dynamics of Research and Development
Harper & Row: New York.

Roberts E. B. (1974)
A simple model of R&D project dynamics
R&D Management 5(1).
Reprinted in Roberts E. B. (ed.). (1978)
Managerial Applications of System Dynamics.
Productivity Press: Cambridge, MA.

Robinson, C. (1993)
Real World Research: A Source of Social Scientists and Practitioner Researchers
Blackwell Publications, Cambridge, MA

Roethlisberger, F. (1977)
The Elusive Phenomena
Boston: Harvard Business School Press.

Rook, P. (1986)
Controlling Software Projects
Software Engineering Journal, January 1986

Rossel, P. (2011)
Beyond the obvious: Examining ways of consolidating early detection schemes
Technological Forecasting & Social Change Vol. 78, pp. 375–385

Rossel, P. (2012)
Early detection, warnings, weak signals and seeds of change: A turbulent domain of futures studies
Futures, Vol. 44, pp. 229–239

Sandberg, J., Alvesson, M. (2011)
Ways of constructing research questions: gap-spotting or probematization?
Organization, Vol: 18, Iss: 1, pp. 23 – 44

Sauer, C., Reich, B. H. (2007)
Guest editorial: What do we want from a theory of project management? A response to Rodney Turner
International Journal of Project Management, Vol. 25, pp. 1–2

Schofield, J., Wilson, D.C. (1995)
The role of capital investment project teams in organisational learning
Scandinavian Journal of Management, Vol. 11, Iss. 4, pp. 423-436

Schwandt, T. A. (2003)
Three Epistemological Stances for Qualitative Inquiry
Interpretivism, Hemeneutics and Social Constructionism
In: Denzin and Lincoln 2003)
Handbook of Qualitative Research (2nd ed)
Sage Publications

Shar, S. K., Corley, K. G. (2006)
Building Better Theory by Bridging the Quantitative–Qualitative Divide
Journal of Management Studies Vol. 43, Iss. 8, pp. 1821-1835

Shenhar, A. J., Dvir, D. (1996)
Toward a typological theory of project management
Research Policy, Vol. 25, pp. 607-632

Shenhar, A., Dvir, D. (2007a)
Project management research: the challenge and opportunity
Project Management Journal, Vol. 38, pp. 93–99

Shokri-Ghasabeh, M., Kavousi-Chabok, K. (2009)
Generic Project Success and Project Management Success Criteria and Factors: Literature Review and Survey
WSEAS Transactions on Business and Economics, Issue 8, Volume 6, pp. 456-468

Simon, H. (1976)
Administrative Behavior (3rd edition)
New York: The Free Press.

Simon. H. A. (1969, 1st edition)
The Sciences of the Artificial
MIT Press, Cambridge, Mass

Simon, H. A. (1996, 3rd edition)
The Sciences of the Artificial
The MIT Press

Smith, A. (1789)
“Chapter I: Of the Division of Labour.”
In: An Inquiry into the Nature and Causes of the Wealth of Nations,
Edited by E. Cannan, 5th ed, 1–11. Glasgow: University of Glasgow.

Smith, M. K. (2009)
Innovation Activities in Call and Contact Centres – An Exploratory Study
PhD Thesis – University of Strathclyde
http://ethos.bl.uk/Home.do

Smyth, H., Morris, P. W. G. (2007)
An epistemological evaluation of research into projects and their management: Methodological issues
International Journal of Project Management, Vol. 25, pp. 423–436

Söderholm, A. (2008)
Project management of unexpected events
International Journal of Project Management, Vol. 26, pp. 80–86

Söderlund, J. (2002)
On the development of project management research: schools of thought and critique.
International Project Management Journal, Vol. 6, pp. 20–31.

Söderlund, J. (2004a)
Building theories of project management: past research, questions for the future
International Journal of Project Management, Vol. 22, pp. 183–191

Söderlund, J. (2004b)
On the broadening scope of the research on projects: a review and a model for analysis
International Journal of Project Management, Vol. 22, pp. 655–667

Söderlund, J. (2011)
Pluralism in Project Management: Navigating the Crossroads of Specialization and Fragmentation
International Journal of Management Reviews, Vol. 13, pp. 153–176

Souza dos Santos, F. R., Cabral, S. (2008)
FMEA and PMBOK Applied to Project Risk Management
Journal of Information Systems and Technology Management, Vol. 5, No. 2, pp. 347-364

Stake, R.E. *(1995)*
The art of case study research,
edn. London: Sage Publications.

Standish (1994)
The Chaos Report (1994)
http://www.standishgroup.com/sample_research_files/chaos_report_1994.pdf

Stanleigh, M. (1999)
Managing a project...from A to Z
Proceedings of the 1999 ASQ's 53rd Annual Quality Congress; Anaheim, CA, USA; 24 May 1999 through 26, pp. 405-413

Stinchcombe, A. L. (1968)
Constructing Social Theories
New York: Harcourt, Brace & World.

Subramanian, G. H., Jiang, J. J., Klein, G. (2007)
Software quality and IS project performance improvements from software development process maturity and IS implementation strategies
The Journal of Systems and Software, Vol. 80, pp. 616–627

Swan, J., Scarbrough, H., Newell, S. (2010)
Why don't (or do) organizations learn from projects?
Management Learning Vol. 41, Iss. 3, pp. 325–344

Symon, G., Cassell, C. (2012)
Qualitative organizational research: core methods and current challenges
London: SAGE

Taylor, F. W. (1911)
The Principles of Scientific Management.
New York: Harper & Brothers.

Taylor, T., Ford, D. N. (2006)
Tipping point failure and robustness in single development projects
System Dynamics Review, Vol. 22, No. 1, pp. 51–71

Teng, S-H. (G)., Ho, S-Y. (M). (1996)
Failure mode and effects analysis; An integrated approach for product design and process control
International Journal of Quality & Reliability Management, Vol. 13 No. 5, pp. 8-26

Themistocleous, G., Wearne, S.H. (2000).
Project management topic coverage in journals.
International Journal of Project Management, Vol. 18, pp. 7–11.

Tishler, A., Dvir, D., Shenhar, A., Lipovetsky, S. (1996)
Identifying Critical Success Factors in Defense Development Projects: A Multivariate Analysis
Technological Forecasting and Social Change 51, pp. 151-171

Too, E. G., Weaver, P. (2013)
The management of project management: A conceptual framework for project governance
International Journal of Project Management, Vol. 32, pp. 1382-1394

Tranfield, D. (2002a)
Formulating the Nature of Management Research
European Management Journal Vol. 20, No. 4, pp. 378–382

Tranfield, D. (2002b)
Future Challenges for Management Research
European Management Journal, Vol. 20, No. 4, pp, 409 – 413

Tranfield, D., Denyer, D., Smart, P. (2003)
Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review
British Journal of Management, Vol. 14, pp. 207-222

Tranfield, D. Starkey, K. (1998)
The Nature, Social Organisation and Promotion of Management Research: Towards Policy
British Journal of Management, Vol. 9, pp 341-353

Turner, J. R. (2006a)
Towards a theory of project management: The nature of the project
International Journal of Project Management, Vol. 24, pp. 1–3

Turner, J. R. (2006b)
Towards a theory of project management: The nature of the project governance and project management
International Journal of Project Management, Vol. 24, pp. 93-95

Turner, J. R. (2006c)
Towards a theory of Project Management: The functions of Project Management
International Journal of Project Management, Vol. 24, pp. 187-189

Turner, J. R. (2006d)
Towards a theory of project management: The nature of the functions of project management
International Journal of Project Management, Vol. 24, pp. 277-279

Turner, J. R., Mű̋ller, R. (2003)
On the nature of the project as a temporary organization
International Journal of Project Management, Vol. 21, pp. 1–8

Tuuli, M.M., Rowlinson, S., Koh, T.Y., (2009)
Portfolio of control modes in project teams: a Hong Kong case study.
In: Dainty, A. (ed)
Proceedings of the 25th Annual ARCOM Conference, 7-9 September 2009, Nottingham, UK,
Association of Researchers in Construction Management, pp. 927-37.

Uppal, K. B. (2009)
Cost Estimating, Project Performance and Life Cycle
AACE International Transactions

Urli, B., Urli, D. (2000)
Project Management in North America, Stability of the Concepts
Project Management Journal, September 2000

Van Aken, J.E. (2004),
Management research based on the paradigm of the design sciences: the quest for field-tested and grounded technological rules
Journal of Management Studies, Vol. 41 No. 2, pp. 219-46.

Van Aken, J.E. (2005)
Management research as a design science: articulating the research products of Mode 2 knowledge production in management
British Journal of Management, Vol. 16 No. 1, pp. 19-36.

Van Aken, J. E., Romme, G. (2009)
Reinventing the future: adding design science to the repertoire of organization and management studies
Organization Management Journal (2009) 6, pp. 5– 12

Van de Ven, A. H. (1989)
Nothing is quite so practical as a good theory
Academy of Managemenl Review. 1989, Vol. 14, No. 4, pp. 486-489

Van de Ven, A. (2000)
"Professional Science for a Professional School."
In Beer, M. and Nohria, N. (Eds),
Breaking the Code of Change.
Boston: Harvard Business School Press.

Van Maanen, J., Sørensen, J. B., and Mitchell, T. R. (2007)
The interplay between theory and method
Academy of management review, Vol. 32, no. 4, pp.1145–1154.

Voordijk, H. (2009)
Construction management and economics: the epistemology of a multidisciplinary design science
Construction Management and Economics, Vol. 27 Iss. 8, pp. 713-720

Voordijk, H. (2011)
Construction management research at the interface of design and explanatory science
Engineering, Construction and Architectural Management, Vol: 18, Iss: 4, pp. 334-342

Wacker, J. G. (2008)
A Conceptual Understanding of Requirements for Theory-Building Research: Guidelines For Scientific Theory Building
Journal of Supply Chain Management, July 2008, pp. 5-15

Weaver (website)
http://www.mosaicprojects.com.au/Resources_Papers.html#Top

Weaver, P. (2007)
The origins of modern project management
Fourth Annual PMI College of Scheduling Conference
15 – 18 April 2007, Marriott Pinnacle Downtown, Vancouver
http://www.mosaicprojects.com.au/Resources_Papers_050.html

Weaver P. (2008)
A Brief History of Scheduling - Back to the Future –
PM World Today - February 2008 (Vol. X, Issue II), pp. 1-18

Weick, K. (1989)
Theory Construction as Disciplined Imagination
Academy of Management Review, Vol. 14, pp.516-532.

Whetten, D. A. (1989)
What Constitutes a Theoretical Contribution?
Academy of Management Review, Vol. 14, No. 4, 490-495

White, B. (2000)
Dissertations skills for business and management students
edn. London: Cassell Publisher.

White, D., Fortune, J. (2002)
Current practice in project management – an empirical study
International Journal of Project Management, Vol. 20, pp.1 – 11

Whitley R. (1984a)
The Fragmented State of Management Studies: Reasons and Consequences
Journal of Management Studies, Vol. 21, Iss. 3, pp.331-348

Whitley R. (1984b)
The Scientific Status of Management Research as a Practically-Oriented Social Science
Joumal of Management Studies, Vol. 21, Iss. 4, pp. 369-390

Williams T. M. (1996)
The two-dimensionality of project risk
International Journal of Project Management, Vol. 14, No. 3, pp. 185-186

Willmot, H. (2012)
Reframing Relevance as ‘Social Usefulness’: A Comment on Hodgkinson and Starkey’s ‘Not Simply Returning to the Same Answer Over and Over Again’
British Journal of Management, Vol. 23, pp. 598–604

Wilson, J. M. (2003)
Gantt charts: A century appreciation
European Journal of Operational Research, 149, pp. 430-437

Winch, G., Pinto, J. (2013)
Festscrift for Professor Peter W. G. Morris, Ph.D.
International Journal of Project Management Vol. 31, Iss. 7. pp. 937

Winter, M., Smith, C. (2006)
Rethinking Project Management – Final Report
EPSRC Network 2004 – 2006

Winter, M., Smith, C., Morris, P., Cicmil, S. (2006)
Directions for future research in project management: The main findings of a UK government-funded research network
International Journal of Project Management, Vol. 24, pp.638–649

Winter, M. Szczepanek, T. (2009)
Images of Projects
Gower Publishing Limited, Farnham, England

Yin, R. (1984)
Case Study Research
Beverly Hills: Sage Publications.

Yin, R. (1994)
Case study research- design and methods
Sage Publications.

Yin, R. K. (2009)
Case Study Research Design and Methods (4th Edition)
Sage Publications

Zheng, L. Y., McMahon, C. A., Li, L., Ding, L., Jamshidi, J. (2008)
Key characteristics management in product lifecycle management: a survey of methodologies and practices
Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 222, pp. 989-1008

Zickert, F., Beck, R. (2013)
A mapping model for assessing project effort from requirements
Information Systems E-Business Management, Vol. 11, pp. 377–401

Zobel, A. M., Wearne, S. H. (2000)
Project management topic coverage in recent conferences
Project Management Journal, Vol. 31, Iss. 2, pp. 32–37

APPENDICES

Appendix A Success Criteria

**Table 70:	Success criteria (part 1)**

Factor	Pinto & Prescott (1988)	Shenhar et al (1997)	Verner et al (1999)	Boyd (2001)	Cooke-Davies (2002)	Andersen et al (2006)	Shokri-Ghasabeh & Kavousi-Chabok (2009)	Cerpa & Verner (2009)
Time		Meeting time goals		Deliver the project in a timeframe the customer desires or needs;	Keep project (or project stage duration) as far below 3 years as possible (1 year is better).	Project execution flexibility	Time	Delivery date impacted the development process
								Aggressive schedule affected team motivation
								Schedule had a negative effect on team member's life
Cost		Meeting budget goals	Accurate developer-driven estimates	Deliver quality consistent with the price;			Cost	Project under-estimated
Scope			Appropriate lifecycle models				Scope	Process did not have reviews at the end of each phase
								Scope changed during the project

Table 71: Success criteria (part 2)

Factor	Pinto & Prescott (1988)	Shenhar et al (1997)	Verner et al (1999)	Boyd (2001)	Cooke-Davies (2002)	Andersen et al (2006)	Shokri-Ghasabeh & Kavousi-Chabok (2009)	Cerpa & Verner (2009)
Quality (Specification / requirements)	Project Mission. Initial clarity of goals and general directions.	Meeting operational specifications	Negotiated, well defined requirements	Project objectives not fully specified;		Well understood and accepted project purpose	Quality	Delivery decision made without adequate requirements information
	Project Schedule/Plan. A detailed specification of the individual action steps required for project implementation.	Meeting technical specifications				Clear project constraints		Customers/Users did not make adequate time available for requirements gathering
Stakeholders	Client Acceptance. The act of "selling" the final project to its ultimate intended users.	Fulfilling customer needs		Deliver the product that the customer desires or needs;		Early stakeholder influence		Customer/Users had unrealistic expectations
		Actually used by the customer						
Top Management Support	Top Management Support. Willingness of top management to provide the necessary resources and authority/power for project success.		High-Level Management Support			Strong project commitment	Top Management Support	

Table 72: Success criteria (part 3)

Factor	Pinto & Prescott (1988)	Shenhar et al (1997)	Verner et al (1999)	Boyd (2001)	Cooke-Davies (2002)	Andersen et al (2006)	Shokri-Ghasabeh & Kavousi-Chabok (2009)	Cerpa & Verner (2009)
Project Team	Personnel. Recruitment, selection, and training of the necessary personnel for the project team.		Low Staff Turnover Experienced Project Manager	Insufficient senior staff on the team;	Adequacy of documentation of organisational responsibilities on the project.		Project Team	Staff were not rewarded for working long hours Staff had an unpleasant experience working on the project
Contracts		Level of commercial success Generated a large market share Opened a new market Opened a new line of products		bad planning and estimating;			Contracts	
Risk			Managed Risk	Have a system of conflict resolution that is fair to both the customer and the development team.	Adequacy of company-wide education on the concepts of risk management Maturity of an organisation's processes for assigning ownership of risks. Adequacy with which a visible risk register is maintained. Adequacy of an up-to-date risk management plan.		Risk Management	Risks were not re-assessed, controlled, or managed through the project Risk not incorporated into the project plan

Table 73: Success criteria (part 4)

Factor	Pinto & Prescott (1988)	Shenhar et al (1997)	Verner et al (1999)	Boyd (2001)	Cooke-Davies (2002)	Andersen et al (2006)	Shokri-Ghasabeh & Kavousi-Chabok (2009)	Cerpa & Verner (2009)
Resource				Poor performance by supplier s of hardware/software;	Portfolio- and programme management practices that allow the enterprise to resource fully a suite of projects that are thoughtfully and dynamically matched to the corporate strategy and business objectives.		Resource Availability	Project had inadequate staff to meet the schedule
				performance problems.				Staff added late to meet an aggressive schedule

Table 74: Success criteria (part 5)

Factor	Pinto & Prescott (1988)	Shenhar et al (1997)	Verner et al (1999)	Boyd (2001)	Cooke-Davies (2002)	Andersen et al (2006)	Shokri-Ghasabeh & Kavousi-Chabok (2009)	Cerpa & Verner (2009)
Project Control / Process	Monitoring and Feedback. Timely provision of comprehensive control information at each stage in the implementation process.			inadequate/no project management methodology	Maintain the integrity of the performance measurement baseline	Well structured and formal project approach	Project Control	Development Methodology was inappropriate for the project
					A suite of project, programme and portfolio metrics that provides direct "line of sight" feedback on current project performance, and anticipated future success, so that project, portfolio and corporate decisions can be aligned.	Influence over on-going project processes		

Table 75: Success criteria (part 6)

Factor	Pinto & Prescott (1988)	Shenhar et al (1997)	Verner et al (1999)	Boyd (2001)	Cooke-Davies (2002)	Andersen et al (2006)	Shokri-Ghasabeh & Kavousi-Chabok (2009)	Cerpa & Verner (2009)
Project Change					Allow changes to scope only through a mature scope change control process.		Project Change	Change control not monitored, nor dealt with effectively
Communications	Communication. The provision of an appropriate network and necessary data to all key actors in the project implementation		High Intra-Team Communications			Rich project communications		
Technology	Technical Tasks. Availability of the required technology and expertise to accomplish the specific technical action steps.	Developed a new technology		technology new to the organisation				

Table 76: Success criteria (part 7)

Factor	Pinto & Prescott (1988)	Shenhar et al (1997)	Verner et al (1999)	Boyd (2001)	Cooke-Davies (2002)	Andersen et al (2006)	Shokri-Ghasabeh & Kavousi-Chabok (2009)	Cerpa & Verner (2009)
Troubleshooting	Trouble-Shooting. Ability to handle unexpected crises and deviations from plan.	Solving major operational problems						
Benefits management					The existence of an effective benefits delivery and management process that involves the mutual co-operation of project management and line management functions.			
Learning from experience					An effective means of "learning from experience" on projects, that combines explicit knowledge with tacit knowledge in a way that encourages people to learn and to embed that learning into continuous improvement of project management processes and practices. Indeed, for Kerzner [11], continuous improvement represents the fifth and highest stage of project management maturity in an organization			

Appendix B Case study (1): LIFECar

B.1 Theme 1: “Group Composition”

B.1.1 FMEA

Table 77: Coley (2008): Theme 1: “Group Composition” FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Group Composition								
	Time	Schedule delays to project	7	Subcontractors will select personnel according to their own process	5	Consider specific constraints on sub-contractors – include as risk?	7	245
	Project Change	Delivered product does not meet requirements	8	Group members avoid raising change requirements	5	Management review	5	200
	Time	Schedule delays to project	5	Selected personnel are unable to support the required timescales	5	Re-planning project as goals are not achieved	7	175
	Top Management Support	Support within partner organisations	6	Management within partner organisations who are not involved in this project diverting personnel to other work	5	Sub-contract review	5	150
	Project Team	Change to partner organisations	6	Project partner undergoes internal re-organisation	5	Contract clause – to provide support during re-organisation activity to minimise impact on project progress.	5	150
	Stakeholders	Priority of resources within partner organisations	6	Facilities and equipment may be prioritised to other tasks	4	Agreement between partners of resource and equipment commitment required. Detail progress monitoring and communication with partners to ensure commitments are being met.	6	144
	Quality	Failure to deliver customer requirements	7	Failure to analyse customer requirements and associate with skills of personnel	5	Design review including customer agreement	4	140
	Troubleshooting	Problems remain unresolved	7	Dispersed teams & sub-contractors make troubleshooting difficult	5	Team leaders review of group and local team management	4	140
	Resources	Sub-contractor resource	7	Focus on delivery rather than selection of right people	6	Skills mapping / matrix	3	126
	Cost	Cost increases	8	Group awareness of costs is insufficient	5	Tracking of expenditure purchase agreements	3	120

B.1.2 WS-TP Analysis

Table 78: Coley (2008): Theme 1: "Group Composition" WS TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	RPN	Weak Signals	Tipping Point
Group Composition						
	Time	Schedule delays to project	Subcontractors will select personnel according to their own process	245	Sub-contractor specialist unavailable to attend review meeting. Sub-contractors do not provide clear evidence of actions to support schedule	Sub-contractor specialist does not attend multiple review meetings. Sub-contractors do not provide clear evidence of actions to support schedule at subsequent review
	Project Change	Delivered product does not meet requirements	Group members avoid raising change requirements	200	It is clear that a 'new' issue has earlier origins and could have been raised at previous management reviews. Group members change and require time to get up the learning curve	It is clear that a 'new' issue has earlier origins and could have been raised at previous management reviews – remains unresolved. More than one group members change
	Time	Schedule delays to project	Selected personnel are unable to support the required timescales	175	Any task that requires re-planning due to change in group composition – particularly if there is a clear schedule impact.	On-going requirement for re-planning due to change in group composition – particularly if there is a clear schedule impact.
	Top Management Support	Support within partner organisations	Management within partner organisations who are not involved in this project diverting personnel to other work	150	Review with partners delayed due to 'personnel' issues	Review with partners delayed due to 'personnel' issues – continues over a second review meeting.
	Project Team	Change to partner organisations	Project partner undergoes internal re-organisation	150	Sub-contractor specialist unavailable to attend review meeting. Sub-contractors do not provide clear evidence of actions to support schedule	Sub-contractor specialist unavailable to attend second review meeting. Sub-contractors do not provide clear evidence of actions to support schedule at subsequent review
	Stakeholders	Priority of resources within partner organisations	Facilities and equipment may be prioritised to other tasks	144	Any attempt to change previously agreed resource plan where it is not clear that an attempt is being made to improve the project deliverables. Or, case where a conflict between stakeholders is raised but the other project/task gains priority.	Any attempt to change previously agreed resource plan where it is not clear that an attempt is being made to improve the project deliverables. Or, case where a conflict between stakeholders is raised but the other project/task gains priority. Where these issues extend to a second review.
	Quality	Failure to deliver customer requirements	Failure to analyse customer requirements and associate with skills of personnel	140	Requirements review (particularly if close to major design review) identifies issues with meeting requirements.	Requirements review (particularly if close to major design review) identifies issues with meeting requirements is on-going.
	Troubleshooting	Problems remain unresolved	Dispersed teams & sub-contractors make troubleshooting difficult	140	Second occurrence of a previously identified problem – where previous troubleshooting may have resolved the problem	Second occurrence of a previously identified problem – where previous troubleshooting may have resolved the problem., remains unresolved.
	Resources	Sub-contractor resource	Focus on delivery rather than selection of right people	126	Resource issues remain un-resolved.	Resource issues continue to remain un-resolved.
	Cost	Cost increases	Group awareness of costs is insufficient	120	Task cost increase from plan	Task costs continue to increase from plan

B.2 Theme 2: “Communication”

B.2.1 FMEA

Table 79: Coley (2008): Theme 2: “Communication” FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Pathogens Incubation	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Communication									
	Top Management Support	Contractor management don’t prioritise project tasks leading to delay or project failure	Practice Habituation	8	Lack of priority from top management for specific project	5	Not communicated by top management	5	200
	Communications	All issues around the project are likely to have an aspect of communications	Organisation Complexity	7	Failure to communicate between actors	5	Regular communications meetings	5	175
	Contracts	Lack of communication leads to inappropriate contracts and problems to deliver the project	Circumstance Quantity	8	Understanding project requirements and structuring distribution between prime and sub-contract	6	Contract review	3	144
	Communications	*“This meant that frequently decisions made by one partner were not communicated with the rest of the team. This often resulted in a partner working on part of the design using the wrong dimensions for example”* (Coley 2008)	Organisation Obsolescence	6	*“It appeared that some team members were unaware of the importance and need to communicate information, particularly when making design decisions.”* (Coley 2008)	6	Need to maintain communication between team members	4	144
	Stakeholders	Lack of communication leads to conflict between stakeholders	Organisation Stress	7	Understanding the project structure across stakeholders	5	Contract	4	140
	Project Team	Failure to communicate between project team members leads to problems	Practice Habituation	7	Sub-contract – relationship to prime	5	Prime contractor is not highest priority – not communicated by sub-contractor	4	140
	Cost	Communication failure leads to unnecessary costs	Industry Complexity	5	Sub-contractors have multiple priorities, which are not communicated.	6	Contract	4	120
	Project Control / Process	Inconsistent project controls do not raise issues	Practice Habituation	6	Is common process applied across all stakeholders?	5	Contract agreement on control process to be used	4	120
	Communications	*“This potentially prevented an understanding of how components of the design impacted upon each other. Additionally opportunities for optimisation between components of the design could have been overlooked and this put the realisation of a fully integrated design at risk”* (Coley 2008)	Practice Complexity	6	*Outside of team-meetings, team-members often neglected to communicate frequently and consistently with the whole team.* (Coley 2008)	5	Need to maintain communication between team members	4	120
	Communications	*“On one occasion the delay of an integral part of the design was not communicated to the project team.”* (Coley 2008)	Organisation Obsolescence	5	*“Communication between some companies and the project team was not sufficient.”* (Coley 2008)	6	Need to maintain communication between team members	4	120

B.2.2 WS-TP Analysis

Table 80: Coley (2008): Theme 2: "Communications" WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Communication							
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	Lack of priority from top management for specific project	Not communicated by top management	200	Contractor response times become extended, or have to be chased. Personnel are not available due to other activities.	Top management or contractors management actively prioritise other work
	Communications	All issues around the project are likely to have an aspect of communications	Failure to communicate between actors	Regular communications meetings	175	Need to chase up on communications	Communication activities are cancelled
	Contracts	Lack of communication leads to inappropriate contracts and problems to deliver the project	Understanding project requirements and structuring distribution between prime and sub-contract	Contract review	144	Need to revisit or revise contracts	Contract requires re-negotiation
	Communications	*"This meant that frequently decisions made by one partner were not communicated with the rest of the team. This often resulted in a partner working on part of the design using the wrong dimensions for example"* (Coley 2008)	*"It appeared that some team members were unaware of the importance and need to communicate information, particularly when making design decisions."* (Coley 2008)	Need to maintain communication between team members	144	Evidence that critical information has not been communicated – for example, two parts of the organisation working to different drawing issues standards,	Use of incorrect information is only recognised at a design review
	Stakeholders	Lack of communication leads to conflict between stakeholders	Understanding the project structure across stakeholders	Contract	140	Stakeholder challenges basic objective of the task / project	It becomes clear that a stakeholder has an incorrect understanding of the project
	Project Team	Failure to communicate between project team members leads to problems	Sub-contract – relationship to prime	Prime contractor is not highest priority – not communicated by sub-contractor	140	Evidence of conflict between team members	Team members actively avoid contact which impacts task delivery
	Cost	Communication failure leads to unnecessary costs	Sub-contractors have multiple priorities, which are not communicated.	Contract	120	Any cost increase, or delay to invoicing	Sub-contractor requires revision of costs
	Project Control / Process	Inconsistent project controls do not raise issues	Is common process applied across all stakeholders?	Contract agreement on control process to be used	120	Activities have to be re-visited to ensure correct process	Any impact of the project plan due to revision of task reporting
	Communications	*"This potentially prevented an understanding of how components of the design impacted upon each other. Additionally opportunities for optimisation between components of the design could have been overlooked and this put the realisation of a fully integrated design at risk"* (Coley 2008)	*Outside of team-meetings, team-members often neglected to communicate frequently and consistently with the whole team.* (Coley 2008)	Need to maintain communication between team members	120	Team or review meetings identify communication activities that should have been completed between meetings	Team or review has to be re-scheduled to allow work to be completed or revised
	Communications	*"On one occasion the delay of an integral part of the design was not communicated to the project team."* (Coley 2008)	*"Communication between some companies and the project team was not sufficient."* (Coley 2008)	Need to maintain communication between team members	120	Subsequent task on project plan impacted by completion of previous task	Subsequent task prompts re-plan of the project network

B.3 Theme 3: “Individual Characteristics”

B.3.1 FMEA

Table 81: Coley (2008): Theme 3: “Individual Characteristics” FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Pathogen Incubation	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Individual characteristics									
	Project Change	Ability to recognise impact of change	Practice Habituation	6	Individual focus on activities ignores bigger picture.	5	Individual awareness of change control process	5	150
	Cost	Awareness of costs and individual responsibility for costs	Practice Complexity	7	Project costs increase / exceed contract limit	5	Training	4	140
	Quality	Recognition of need to achieve quality standards	Practice Obsolescence	6	Individuals work to what they think is right with out reference to standards	5	Training	4	120
	Project Team	*“This prevented some team members from consistently seeing the solution as a whole and could have meant that links between sub-systems were not taken advantage of.”* (Coley 2008)	Organisation Habituation	6	*“It was unclear as to whether every member of the team possessed the ability to think systemically.”* (Coley 2008)	5	Skills matrix	4	120
	Risk	Understanding risk	Practice Reinforcement	6	Individuals do not apply sufficient consideration to project risks	5	Risk review process	4	120
	Communications	Impact on subsequent activities requiring rework	Organisation Reinforcement	7	Willingness to communicate between individuals	4	Project progress meetings / reviews	4	112
	Project Control / Process	Ability to apply or support project controls	Tool Reinforcement	7	Lack of understanding of controls process	5	Controls process	3	105
	Project Change	Minimising causes of project change.	Organisation Quantity	5	Individual awareness of impact on overall project objectives	5	Communication of Change control process	4	100
	Troubleshooting	Problems escalate	Practice Stress	5	Individuals do not raise issues that require resolution	5	Skills matrix / match review	4	100

B.3.2 WS-TP Analysis

Table 82: Coley (2008): Theme 3: "Individual Characteristics" WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Individual characteristics							
	Project Change	Ability to recognise impact of change	Individual focus on activities ignores bigger picture.	Individual awareness of change control process	150	Change control requires re-work	Component designs are scrapped and new designs required.
	Cost	Awareness of costs and individual responsibility for costs	Project costs increase / exceed contract limit	Training	140	Individuals prioritise technical issues and do not recognise the need to monitor costs issues within the development activity	Technical activities continue to be pursued according to initial plan despite clear evidence that revision is required.
	Quality	Recognition of need to achieve quality standards	Individuals work to what they think is right with out reference to standards	Training	120	Quality audit identifies individual failure to reference standards	Quality audit raises formal corrective action to achieve quality standards
	Project Team	*"This prevented some team members from consistently seeing the solution as a whole and could have meant that links between sub-systems were not taken advantage of."* (Coley 2008)	*"It was unclear as to whether every member of the team possessed the ability to think systemically."* (Coley 2008)	Skills matrix	120	Members of the project team do not actively relate to the whole solution – they focus on the detail activities	Focus on detail results in failure to meet a systems integration requirement
	Risk	Understanding risk	Individuals do not apply sufficient consideration to project risks	Risk review process	120	Risk reviews result in increasing trend in potential for risks to mature	Risks mature
	Communications	Impact on subsequent activities requiring rework	Willingness to communicate between individuals	Project progress meetings / reviews	112	Lack of communication impacts delivery of project task	Requires re-baseline of the project plan
	Project Control / Process	Ability to apply or support project controls	Lack of understanding of controls process	Controls process	105	Step change in reported status since previous report	Multiple step changes, or a sequence of step changes leads to need to re-baseline project to ensure control is maintained
	Project Change	Minimising causes of project change.	Individual awareness of impact on overall project objectives	Communication of Change control process	100	Cause of project change not recognised prompting rework	Requires re-baseline of the project plan
	Troubleshooting	Problems escalate	Individuals do not raise issues that require resolution	Skills matrix / match review	100	Identification of an issue causes re-work	Identification of an issue causes re-planning

B.4 Theme 4: “Commitment”

B.4.1 FMEA

Table 83: Coley (2008): Theme 4: “Commitment” FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Pathogens Incubation	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Commitment									
	Stakeholders	*“This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required”* (Coley 2008)	Organisation Reinforcement	6	*“It was apparent that some partners were not aware of the level of commitment that was required of them.”* (Coley 2008)	6	Top management commitment to support project	5	180
	Stakeholders	*“This meant that those working full time were constantly waiting for work from other members of the team before they could continue. This caused a sense of frustration”* (Coley 2008)	Circumstance Habituation	6	*“Some actors worked full time on the project whilst other actors worked part time.”* (Coley 2008)	5	Top management commitment to support project progress	5	150
	Stakeholders	Tasks / project fails due to lack of stakeholder commitment	Industry Quantity	7	Stakeholder commitment / other priorities	5	Contract review	4	140
	Top Management Support	Project fails	Practice Habituation	7	Lack of commitment	5	Project review process includes top management	3	105
	Top Management Support	*“This meant that some partners had substantially larger workloads than others.”* (Coley 2008)	Organisation Quantity	5	*“The number of personnel that a company was able to allocate to the project varied between partners.”* (Coley 2008)	4	Top management commitment to support project resource requirements	5	100

B.4.2 WS-TP Analysis

Table 84: Coley (2008): Theme 4: "Commitment" WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Commitment							
	Stakeholders	*"This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required"* (Coley 2008)	*"It was apparent that some partners were not aware of the level of commitment that was required of them."* (Coley 2008)	Top management commitment to support project	180	Multiple attempts are required to ensure stakeholders maintain commitment	Lack of Stakeholder commitment leads to delays in delivering tasks
	Stakeholders	*"This meant that those working full time were constantly waiting for work from other members of the team before they could continue. This caused a sense of frustration"* (Coley 2008)	*"Some actors worked full time on the project whilst other actors worked part time."* (Coley 2008)	Top management commitment to support project progress	150	Delays in obtaining materials from part-time stakeholders impacts task progress	Delays require baseline re-planning
	Stakeholders	Tasks / project fails due to lack of stakeholder commitment	Stakeholder commitment / other priorities	Contract review	140	Delays in obtaining materials from stakeholders, due to their activities on other projects, impacts task progress	Delays require baseline re-planning
	Top Management Support	Project fails	Lack of commitment	Project review process includes top management	105	Lack of top management support impacts task progress	Delays require baseline re-planning
	Top Management Support	*"This meant that some partners had substantially larger workloads than others."* (Coley 2008)	*"The number of personnel that a company was able to allocate to the project varied between partners."* (Coley 2008)	Top management commitment to support project resource requirements	100	Lack of top management support impacts task progress	Delays require baseline re-planning

B.5 Theme 5: "Motivation"

B.5.1 FMEA

Table 85: Coley (2008): Theme 5: "Motivation" FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Pathogens Incubation	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Motivation									
	Scope	Tasks / project delayed	Task Quantity	6	Scope appears unachievable – lack of motivation to deliver scope of project	5	Bid process to scope achievable work	5	150
	Risk	Risks mature	Practice Reinforcement	6	Risk appears significant and adversely affects motivation	5	Risk register	5	150
	Cost	Project delivered over budget	Practice Quantity	6	Motivation to deliver within budget	6	Agreed project plan	4	144
	Contracts	Work does not proceed	Organisation Habituation	7	Contract constrains motivation	5	None	4	140
	Quality	Product does not meet customers requirements	Organisation Complexity	8	*"Due to conflicting goals, compromises within the design had to be agreed upon by partners. This meant that not all individual goals could be achieved. This, however, led to compromises being made between partners. This was essential for the successful development of a final solution."* (Coley 2008)	5	Analysis against project requirements	3	120
	Time	Late delivery of tasks or project	Practice Reinforcement	7	Motivation to deliver on time	5	Agreed project plan	3	105
	Top Management Support	Team motivation fails – project is late or over budget	Organisation Habituation	7	Lack of top management motivation	5	Top management authorisation of project	3	105
	Project Control / Process	Control / process failure leads to additional work and less motivation	Industry Habituation	5	Project does not make required progress due to lack of motivation	4	Project controls exist – but none apply to motivation	5	100
	Communications	Communications drive motivation	Organisation Reinforcement	5	*"An alignment between individual motivations and the overarching motivations of the project needs to be found. Doing this encourages a sense of identity between the project team."* (Coley 2008)	5	Regular communications activities and team building – encouraging individual contribution	4	100

B.5.2 WS-TP Analysis

Table 86: Coley (2008): Theme 5: "Motivation" WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Motivation							
	Scope	Tasks / project delayed	Scope appears unachievable – lack of motivation to deliver scope of project	Bid process to scope achievable work	150	Evidence of a lack of understanding of project scope – such as revisiting previously agreed requirements /scope	Need for revision of plan to deliver task
	Risk	Risks mature	Risk appears significant and adversely affects motivation	Risk register	150	Increase in potential risks – risk mitigation and risk register shows increase in contingency	Risks mature and require redistribution of resource
	Cost	Project delivered over budget	Motivation to deliver within budget	Agreed project plan	144	Any indication of cost creep	Overspend occurs
	Contracts	Work does not proceed	Contract constrains motivation	None	140	Contractual clauses are identified in review of progress	Change or re-negotiation of contract
	Quality	Product does not meet customers requirements	*"Due to conflicting goals, compromises within the design had to be agreed upon by partners. This meant that not all individual goals could be achieved. This, however, led to compromises being made between partners. This was essential for the successful development of a final solution."* (Coley 2008)	Analysis against project requirements	120	Evidence of goal conflict between different stakeholders	Stakeholder focuses on individual rather than project goal
	Time	Late delivery of tasks or project	Motivation to deliver on time	Agreed project plan	105	Any indication of schedule creep	Deliverable is late to schedule
	Top Management Support	Team motivation fails – project is late or over budget	Lack of top management motivation	Top management authorisation of project	105	Top management focus on other priorities	Focus on other priorities leads to delay
	Project Control / Process	Control / process failure leads to additional work and less motivation	Project does not make required progress due to lack of motivation	Project controls exist – but none apply to motivation	100	Indication of project objectives not been assessed by project controls	Project controls identify a clear issue – which due to their inherent lag, will be more significant.
	Communications	Communications drive motivation	*"An alignment between individual motivations and the overarching motivations of the project needs to be found. Doing this encourages a sense of identity between the project team."* (Coley 2008)	Regular communications activities and team building – encouraging individual contribution	100	Stakeholders do not support communications activities	Communications activities are cancelled or significantly delayed.

B.6 Theme 6: “Identity”

B.6.1 FMEA

Table 87: Coley (2008): Theme 6: “Identity” FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Pathogens Incubation	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
identity									
	Scope	Scope creep or schedule / cost increase	Organisation Habituation	5	Contractors other interests override scope due to not identifying with the project	6	None	10	300
	Stakeholders	Task progress slows, because stakeholders are not seen to be focused on task objectives.	Convention Reinforcement	4	Stakeholders retain the identity of their parent organisations / departments	4	None	10	160
	Troubleshooting	Problems take longer to identify and resolve – impacting task performance and causing delay to project	Organisation Quantity	5	Team members operate independently leading to lack of association with issues	3	None	10	150
	Project Change	Required changes are not implemented – incorrect design standard presented at subsequent design review	Practice Complexity	7	Team members do not recognise authority and requirement to support change control process / configuration management activity	4	Change control process and configuration management	5	140
	Project Team	*“This initially prevented the group from forming an identity and meant that becoming a ‘team’ as opposed to a group of people was difficult.”* (Coley 2008)	Task Complexity	6	*“There were a lot of problems during the first year of the project which demotivated the group.”* (Coley 2008)	5	No team events funded in early stages of project to allow team building / identify to develop.	4	120
	Benefits Management	Project team does not realise benefits	Industry Habituation	4	Team members operate independently leading to lack of association with issues	3	None	10	120
	Cost	Lack of team identity leads to difficulty in resolving issues and increased costs	Task Reinforcement	5	Immediate focus on task activity and delivery – limiting opportunity for team identity to develop	5	No team events funded in early stages of project to allow team building / identify to develop.	4	100

B.6.2 WS-TP Analysis

Table 88: Coley (2008): Theme 6: "Identity" WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
identity							
	Scope	Scope creep or schedule / cost increase	Contractors other interests override scope due to not identifying with the project	None	300	Review of scope of specific task	Task scope impacts project network – causing restructuring of project
	Stakeholders	Task progress slows, because stakeholders are not seen to be focused on task objectives.	Stakeholders retain the identity of their parent organisations / departments	None	160	Stakeholder does not provide expected support to project / task	Task requires restructuring due to stakeholders actions or lack of support
	Troubleshooting	Problems take longer to identify and resolve – impacting task performance and causing delay to project	Team members operate independently leading to lack of association with issues	None	150	Issues 'emerge' and are not identified in risk or change control documentation / process	The task cannot be progress until a 'previously unrecognised problem is resolved.
	Project Change	Required changes are not implemented – incorrect design standard presented at subsequent design review	Team members to not recognise authority and requirement to support change control process / configuration management activity	Change control process and configuration management	140	Agreed changes remain within the change control process for an extended period before being implemented	Changes are either not implemented leading to rework, or become a 'panic' to implement when the task becomes critical
	Project Team	*"This initially prevented the group from forming an identity and meant that becoming a 'team' as opposed to a group of people was difficult."* (Coley 2008)	*"There were a lot of problems during the first year of the project which demotivated the group."* (Coley 2008)	No team events funded in early stages of project to allow team building / identify to develop.	120	Stakeholders take a 'contract' approach to the project, focused on delivering specific objectives rather than being part of the overall project team	Lack of stakeholders identify to project leads to failure to meet progress review points
	Benefits Management	Project team does not realise benefits	Team members operate independently leading to lack of association with issues	None	120	Stakeholders do not identify with realisation of benefits	Benefits are not recognised, or do not contribute to improved progress of tasks
	Cost	Lack of team identity leads to difficulty in resolving issues and increased costs	Immediate focus on task activity and delivery – limiting opportunity for team identity to develop	No team events funded in early stages of project to allow team building / identify to develop.	100	Evidence of conflict between stakeholders – not identifying with the project	Failure to meet budget

B.7 Theme 7: "Sense Making"

B.7.1 FMEA

Table 89: Coley (2008): Theme 7: "Sense Making" FMEA (Part 1)

Process Step	Potential Failure Modes	Potential Effects of Failure	Pathogen Incubation	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Sense Making									
	Stakeholders	Schedule Delays / Budget increase	Organisation Reinforcement	5	Integration of individual stakeholders	5	None	10	250
	Quality	Task not delivered to acceptable standard leading to rework and delay impacting project delivery	Practice Complexity	7	Defined standards or procedures do not make sense within specific task activities	7	Initial planning and quality standards / process definition	5	245
	Communications	Product design standard is defined in a multiple of ways and makes no sense causing confusion leading to rework and delay / cost increase -	Task Complexity	7	*"This was difficult as other partners were not able to fully comprehend what they were explaining"* (Coley 2008)	7	*"Partners communicated initially using their own terminology." (Coley 2008)*	4	196
	Cost	*"This led to confusion surrounding roles and responsibilities"* (Coley 2008)	Tool Habituation	6	*"Due to the Funding Call process, stipulated by the funding body and discussed in Section 5.3.1, there was insufficient time to fully explore each partner's requirements and expectations of the project."* (Coley 2008)	7	Initial planning and bid process	4	168
	Troubleshooting	Issues are not identified or resolved and may be repeated	Convention Obsolescence	4	No common approach to trouble shooting	4	None	10	160

Table 90: Coley (2008): Theme 7: "Sense Making" FMEA (Part 2)

Process Step	Potential Failure Modes	Potential Effects of Failure	Pathogen Incubation	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Sense Making									
	Technology	Task delays / cost increase due to confusion on task progress	Task Obsolescence	5	Lack of knowledge about product design standard makes no sense causing confusion	6	*"Knowledge about the relationships and interfaces between different disciplines and subsequent sub-systems creates a joint architecture through which components can be developed in alignment with the whole system."* (Coley 2008)	5	150
	Stakeholders	Time taken for different perspectives to be understood and integrated impacts task progress.	System Reinforcement	6	*"Actors from different organisations were accompanied by unique perspectives, ideas and knowledge. This is essential to develop a whole systems perspective"* (Coley 2008)	6	Initial planning and stakeholder involvement	4	144
	Communications	*"Subsequently communication was much more efficient which substantially enabled progress"* (Coley 2008)	Organisation Obsolescence	6	Prior to a common understanding being established communications would cause confusion and information might not make sense leading to rework	6	*"Over time partners established a common language in which to communicate their ideas between the team. This was established due to an understanding of the terminology used within each of the sub-systems."* (Coley 2008)	4	144
	Scope	Time to adopt new practice impacts task / project schedule	Practice Complexity	5	*"The whole system design process is different from a traditional design process. Partners found whole system design uncertain as frequently they could not make decisions surrounding their own part of the design until other design decisions had been made in other parts of the system. Actors were observed to spend time identifying differences between the emergent and organic whole system design process and their usual, more structured, practice. This enabled these differences to be addressed and the new design process to be adopted"* (Coley 2008)	7	Initial planning and process definition	4	140
	Time	Impact on other tasks leads to project delays	Task Quantity	7	Not recognising integration of specific task timescales within overall project timescales	6	Project plan	3	126

B.7.2 WS-TP Analysis

Table 91: Coley (2008): Theme 7: "Sense Making" WS-TP (Part 1)

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Sense Making							
	Stakeholders	Schedule Delays / Budget increase	Integration of individual stakeholders	None	250	Progress activities delayed due to stakeholders actions	Task completion or design review incomplete / delayed due to stakeholder actions
	Quality	Task not delivered to acceptable standard leading to rework and delay impacting project delivery	Defined standards or procedures do not make sense within specific task activities	Initial planning and quality standards / process definition	245	Need to revise / re-write task definition	Quality failure identified
	Communications	Product design standard is defined in a multiple of ways and makes no sense causing confusion leading to rework and delay / cost increase -	*"This was difficult as other partners were not able to fully comprehend what they were explaining"* (Coley 2008)	*"Partners communicated initially using their own terminology." (Coley 2008)*	196	Indication of misunderstanding of product design standards between stakeholders.	Communications have to be revised .
	Cost	*"This led to confusion surrounding roles and responsibilities"* (Coley 2008)	*"Due to the Funding Call process, stipulated by the funding body.......there was insufficient time to fully explore each partner's requirements and expectations of the project."* (Coley 2008)	Initial planning and bid process	168	Evidence of partners failing to make sense of the breakdown of roles and responsibilities leads to cost increase	Stakeholder conducts incorrect work – due to confusion / lack of sense making
	Troubleshooting	Issues are not identified or resolved and may be repeated	No common approach to trouble shooting	None	160	An issue remains unresolved.	Progress review does not meet expectations due to previously identified issue not being resolved.
	Technology	Task delays / cost increase due to confusion on task progress	Lack of knowledge about product design standard makes no sense causing confusion	*"Knowledge about the relationships and interfaces between different disciplines and subsequent sub-systems creates a joint architecture through which components can be developed in alignment with the whole system."* (Coley 2008)	150	Technology mismatch between stakeholders results in confusion or source of sense-making failure	Incompatible technology (e.g. different software) is not identified during bid / early planning stage leading to impact on task / project whilst problem is resolved

Table 92: Coley (2008): Theme 7: "Sense Making" WS-TP (Part 2)

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Sense Making							
	Stakeholders	Time taken for different perspectives to be understood and integrated impacts task progress.	*"Actors from different organisations were accompanied by unique perspectives, ideas and knowledge. This is essential to develop a whole systems perspective"* (Coley 2008)	Initial planning and stakeholder involvement	144	Different stakeholders perspectives leads to confusion / conflict	Conflict impacts task / project progress
	Communications	*"Subsequently communication was much more efficient which substantially enabled progress"* (Coley 2008)	Prior to a common understanding being established communications would cause confusion and information might not make sense leading to rework	*"Over time partners established a common language in which to communicate their ideas between the team. This was established due to an understanding of the terminology used within each of the sub-systems."* (Coley 2008)	144	Suggestion that stakeholders are not making sense of requirements	There is a clear misunderstanding of communications between stakeholders – identifying a failure in consistent sense making between stakeholders
	Scope	Time to adopt new practice impacts task / project schedule	*"The whole system design process is different from a traditional design process. Partners found whole system design uncertain as frequently they could not make decisions surrounding their own part of the design until other design decisions had been made in other parts of the system. Actors were observed to spend time identifying differences between the emergent and organic whole system design process and their usual, more structured, practice. This enabled these differences to be addressed and the new design process to be adopted"* (Coley 2008)	Initial planning and process definition	140	Stakeholders take time to make sense of new practices, impacting task / project progress	Adoption of new practice leads to task completion / design review delay
	Time	Impact on other tasks leads to project delays	Not recognising integration of specific task timescales within overall project timescales	Project plan	126	Schedule issues impact task / project progress	Task completion or design review delayed

B.8 Theme 8: Managing Uncertainty

B.8.1 FMEA

Table 93: Coley (2008): Theme 8: "Managing Uncertainty" FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Pathogens Incubation	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Managing Uncertainty									
	Quality	Wrong quality specification	Practice Habituation	7	Required quality standard not applied causing uncertainty	6	Definition of Quality Standards and Procedures	5	210
	Stakeholders	Failure to deliver	Organisation Complexity	6	Underlying stakeholder issues not identified	7	Planning and Contingency	5	210
	Scope	Wrong scope delivered due to uncertainty	Task Quantity	7	Insufficient understanding of scope causes uncertainty	6	Scope definition as part of bid process – ensure clear definition of project boundaries	4	168
	Risk	Major risks mature	Practice Reinforcement	7	Scope of risk assessment is limited leading to uncertainty and lack of contingency	6	Risk register / management / Review – management reserve / contingency	4	168
	Troubleshooting	'uncertain' Issues are not identified or resolved and may be repeated	Organisation Habituation	4	No common approach to trouble shooting	4	None	10	160
	Project Control / Process	*"This meant that decisions could have a negative impact if a good understanding of other sub-systems and the relationships that linked them was not present."* (Coley 2008)	Organisation Complexity	6	*"Every design decision made has an impact upon other sub-systems and the final design solution as a whole"* (Coley 2008)	5	Project control / process should highlight potential areas of uncertainty – and process should require local review to assess	5	150
	Project Team	Failure of team to deliver	Task Complexity	6	Project team haven't fully grasped requirements – uncertainties in workload and completion	6	Scope and requirements communication to project team – understanding of risks	4	144
	Risk	Risks mature impacting task / project progress	Practice Habituation	7	Risks not clearly identified	5	Risk register / management / Review	4	140
	Top Management Support	Top management focus on other priorities	Industry Reinforcement	6	Top management lack understanding of project leading to uncertainty of its completion	4	Bid process and Top management approval of project plan	5	120
	Risk	Multiple minor risks mature impacting task / project performance	Practice Quantity	5	Scope of risk assessment is limited leading to uncertainty and lack of contingency	6	Risk register / management / Review	4	120

B.8.2 WS-TP Analysis

Table 94: Coley (2008): Theme 8: “Managing Uncertainty” WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Managing Uncertainty							
	Quality	Wrong quality specification	Required quality standard not applied causing uncertainty	Definition of Quality Standards and Procedures	210	Mis-interpretation of requirement leads to wrong quality specification being used resulting in uncertainty	Quality process error is not detected until audit activity, resulting corrective action that impacts task completion.
	Stakeholders	Failure to deliver	Underlying stakeholder issues not identified	Planning and Contingency	210	Stakeholder understanding / issues leads to uncertainty	Stakeholder activities cause task delivery to be delayed
	Scope	Wrong scope delivered due to uncertainty	Insufficient understanding of scope causes uncertainty	Scope definition as part of bid process – ensure clear definition of project boundaries	168	Scope uncertainty emerges	Task completion or design review identified scope error
	Risk	Major risks mature	Scope of risk assessment is limited leading to uncertainty and lack of contingency	Risk register / management / Review – management reserve / contingency	168	Identified major risks mature requiring contingency to be applied	Multiple major risks mature, or continue to be un-resolved
	Troubleshooting	‘uncertain’ Issues are not identified or resolved and may be repeated	No common approach to trouble shooting	None	160	Troubleshooting activities do not identify uncertainty	Troubleshooting issues require significant activity to investigate and define / apply corrective action impacting task / project progress
	Project Control / Process	*“This meant that decisions could have a negative impact if a good understanding of other sub-systems and the relationships that linked them was not present.”* (Coley 2008)	*“Every design decision made has an impact upon other sub-systems and the final design solution as a whole”* (Coley 2008)	Project control / process should highlight potential areas of uncertainty – and process should require local review to assess	150	Project controls and process do not resolve uncertainty issues	Uncertainty issues are identified as unresolved at design reviews
	Project Team	Failure of team to deliver	Project team haven't fully grasped requirements – uncertainties in workload and completion	Scope and requirements communication to project team – understanding of risks	144	Failure to identify uncertainty issues impacts project teams ability to deliver tasks	Uncertainty issues are not resolved delaying task / project progress
	Risk	Risks mature impacting task / project progress	Risks not clearly identified	Risk register / management / Review	140	Multiple risks mature impacting focus on tasks	Risks require ongoing activity to resolve
	Top Management Support	Top management focus on other priorities	Top management lack understanding of project leading to uncertainty of its completion	Bid process and Top management approval of project plan	120	Lack of top management support delays task progress	Top management focus on other priorities does not allow task / project issues to be resolved
	Risk	Multiple minor risks mature impacting task / project performance	Scope of risk assessment is limited leading to uncertainty and lack of contingency	Risk register / management / Review	120	Multiple minor risks mature impacting focus on tasks	Risks require ongoing activity to resolve

B.9 Theme 9: “Collaboration”

B.9.1 FMEA

Table 95: Coley (2008): Theme 9: “Collaboration” FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Pathogen Incubation	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Collaboration									
	Stakeholders	Schedule Delays / Budget increase	Organisation Complexity	5	Integration of individual stakeholders into collaborative structure	5	None	10	250
	Quality	Task not delivered to acceptable standard leading to rework and delay impacting project delivery	Practice Obsolescence	7	Defined standards or procedures do not integrate within collaboration structure	7	Initial planning and quality standards / process definition	4	196
	Troubleshooting	Issues are not identified or resolved and may be repeated	Industry Habituation	4	No common approach to trouble shooting	4	None	10	160
	Stakeholders	Project failure	Organisation Habituation	6	Failure to recognise the demands of collaboration	5	Project plan / due diligence	5	150
	Time	Impact on other tasks leads to project delays	Organisation Obsolescence	7	Collaboration not being sufficiently integrated to identify specific task timescales within overall project timescales	6	Project plan	3	126
	Scope	Leads to task / project delays	Task Reinforcement	5	Not recognising integration of specific task scope within overall project collaboration structure	6	Initial planning and process definition	4	120
	Top Management Support	Increased work or re-work leading to task / project delay / increased costs	Convention Habituation	6	Top management support and direction does not support collaboration in the context of detailed task activities	5	Top management review and understanding of project plan	4	120
	Benefits Management	Benefits not realised	Tool Reinforcement	3	No common approach to benefits management	4	None	10	120
	Benefits Management	Benefits of collaboration not realised	Organisation Complexity	4	More difficult to realise across collaborative project	3	None	10	120
	Time	Impact on other tasks leads to project delays	Task Complexity	7	Task objectives not recognising collaboration within overall project timescales	5	Project plan and requirements review	3	105

B.9.2 WS-TP Analysis

Table 96: Coley (2008): Theme 9: "Collaboration" WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Collaboration							
	Stakeholders	Schedule Delays / Budget increase	Integration of individual stakeholders into collaborative structure	None	250	Stakeholders objectives do not align to overall aims of collaboration.	Stakeholders fail to deliver to agreement of collaboration, or appear to be delivering 'last minute'.
	Quality	Task not delivered to acceptable standard leading to rework and delay impacting project delivery	Defined standards or procedures do not integrate within collaboration structure	Initial planning and quality standards / process definition	196	Quality issues arise within collaborative organisation (e.g. different standards are used by different stakeholders)	Collaboration quality issues lead to delay of a design review stage or require a design review stage to be revisited.
	Troubleshooting	Issues are not identified or resolved and may be repeated	No common approach to trouble shooting	None	160	Collaboration troubleshooting repetitively identifies the same issues	Collaboration Troubleshooting has not resolved a known issue at subsequent design review.
	Stakeholders	Project failure	Failure to recognise the demands of collaboration	Project plan / due diligence	150	Stakeholders do not apply sufficient attention to project plan detail to fully recognise the collaborative requirements.	Stakeholders do not apply due diligence to recognise the resource demand to meet collaboration objectives.
	Time	Impact on other tasks leads to project delays	Collaboration not being sufficiently integrated to identify specific task timescales within overall project timescales	Project plan	126	Stakeholders do not apply sufficient attention to project plan detail to fully recognise the time commitment required to meet collaborative requirements.	Stakeholders do not apply due diligence to recognise the time demands to meet collaboration objectives.
	Scope	Leads to task / project delays	Not recognising integration of specific task scope within overall project collaboration structure	Initial planning and process definition	120	Stakeholders do not apply sufficient attention to project plan detail to fully recognise the project scope required to meet collaborative requirements.	Stakeholders do not apply due diligence to recognise the project scope to meet collaboration objectives.
	Top Management Support	Increased work or re-work leading to task / project delay / increased costs	Top management support and direction does not support collaboration in the context of detailed task activities	Top management review and understanding of project plan	120	Top Management Support is restricted on resolution of collaboration issues leading to increased work or re-work and task / project delay / increased costs	Lack of top management support leads to identifiable increased work or re-work and task / project delay / increased costs
	Benefits Management	Benefits not realised	No common approach to benefits management	None	120	No common benefits management process between stakeholders	Benefits Management processes does not allow identified benefits to be realised due to process conflict / lack of agreement between stakeholders
	Benefits Management	Benefits of collaboration not realised	More difficult to realise across collaborative project	None	120	No common benefits management process between stakeholders	Implementing an acceptable collaboration Benefits Management process overrides the benefits to be gained.
	Time	Impact on other tasks leads to project delays	Task objectives not recognising collaboration within overall project timescales	Project plan and requirements review	105	Stakeholders not recognising collaboration within overall project timescales	Project progress review fails

B.10 Theme 10: “Ownership”

B.10.1 FMEA

Table 97: Coley (2008): Theme 10: “Ownership” FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Pathogens Incubation	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Ownership									
	Stakeholders	Schedule Delays / Budget increase	Practice Habituation	5	Integration of individual stakeholders	5	None	10	250
	Quality	Task not delivered to acceptable standard leading to rework and delay impacting project delivery	Task Obsolescence	7	Defined standards or procedures do not make sense within specific task activities	7	Initial planning and quality standards / process definition	5	245
	Troubleshooting	Issues are not identified or resolved and may be repeated	Convention Habituation	4	No common approach to trouble shooting	4	None	10	160
	Project Team	*“This led to un-motivated team members and a lack of progress”* (Coley 2008)	Organisation Complexity	5	*“Initially partners were reluctant to take ownership for the project. This was because the project was very ambitious and ambiguous and partners were not willing to ‘jump in’ when it could potentially all go wrong.”* (Coley 2008)	6	Requirements definition, work share and project plan	5	150
	Stakeholders	Time taken for different perspectives to be understood and integrated impacts task progress.	Organisation Reinforcement	6	*“It was decided early on that there was no lead partner and consequently no hard ownership boundaries. This enabled partners to develop a sense of psychological ownership as they all were equally a part of the project”* (Coley 2008)	6	Initial planning and stakeholder involvement	4	144
	Time	Impact on other tasks leads to project delays	Practice Habituation	7	Not recognising integration of specific task timescales within overall project timescales	6	Project plan	3	126
	Time	Impact on other tasks leads to project delays	Organisation Quantity	7	Task objectives not making sense within overall project timescales	6	Project plan and requirements review	3	126
	Scope	Leads to project not making sense	System Quantity	5	Not recognising integration of specific task scope within overall project scope	6	Initial planning and process definition	4	120
	Top Management Support	Increased work or re-work leading to task / project delay / increased costs	Organisation Habituation	5	Top management support and direction does not make sense in the context of detailed task activities	6	Top management review and understanding of project plan	4	120
	Benefits Management	Benefits not realised	Industry Habituation	3	No common approach to benefits management	4	None	10	120

B.10.2 WS-TP Analysis

Table 98: Coley (2008): Theme 10: "Ownership" WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Ownership							
	Stakeholders	Schedule Delays / Budget increase	Integration of individual stakeholders	None	250	Stakeholders do not take ownership of tasks	Stakeholders argue that ownership is responsibility of another actor.
	Quality	Task not delivered to acceptable standard leading to rework and delay impacting project delivery	Defined standards or procedures do not make sense within specific task activities	Initial planning and quality standards / process definition	245	Quality standards are questioned, suggesting stakeholders have not taken ownership of quality requirements.	Quality standards not met, stakeholders clearly not taking ownership of the requirements
	Troubleshooting	Issues are not identified or resolved and may be repeated	No common approach to trouble shooting	None	160	Ownership of troubleshooting issues is disputed, leading to delayed resolution.	Known troubleshooting issues remain unresolved, leading to diversion of resource due to lack of common approach or acceptance of ownership
	Project Team	*"This led to un-motivated team members and a lack of progress"* (Coley 2008)	*"Initially partners were reluctant to take ownership for the project. This was because the project was very ambitious and ambiguous and partners were not willing to 'jump in' when it could potentially all go wrong."* (Coley 2008)	Requirements definition, work share and project plan	150	Project Team members being reluctant to take ownership of tasks due to project ambition and ambiguity.	Early design review activities identifies clear lack of progress towards initial objectives or early stage design review, identified as being due to project team members not accepting ownership of tasks.
	Stakeholders	Time taken for different perspectives to be understood and integrated impacts task progress.	*"It was decided early on that there was no lead partner and consequently no hard ownership boundaries. This enabled partners to develop a sense of psychological ownership as they all were equally a part of the project"* (Coley 2008)	Initial planning and stakeholder involvement	144	Developing stakeholders sense of ownership takes longer that might be anticipated, leading to early delays in progress against 'hard' objectives.	Early design review activities identifies clear lack of progress towards initial objectives or early stage design review, identified as being due to stakeholders not accepting ownership of tasks.
	Time	Impact on other tasks leads to project delays	Not recognising integration of specific task timescales within overall project timescales	Project plan	126	Not taking ownership of time related integration issues leads to task / project delays	Stakeholder focuses on technical aspects, and does not take 'Time Ownership' of task, or need to recognise time integration to other tasks
	Time	Impact on other tasks leads to project delays	Task objectives not making sense within overall project timescales	Project plan and requirements review	126	Not recognising task ownership leads to progress delay	Conflict of time (schedule) objectives is not resolved because stakeholders do not take ownership
	Scope	Leads to project not making sense	Not recognising integration of specific task scope within overall project scope	Initial planning and process definition	120	Not taking ownership of scope related integration issues leads to task / project delays	Conflict of scope objectives is not resolved because stakeholders do not take ownership
	Top Management Support	Increased work or re-work leading to task / project delay / increased costs	Top management support and direction does not make sense in the context of detailed task activities	Top management review and understanding of project plan	120	Top Management Support does not take ownership of issues leading to increased work or re-work and task / project delay / increased costs	Top Management Support does not take ownership or provide direction to resolve issues
	Benefits Management	Benefits not realised	No common approach to benefits management	None	120	Project organisation does not take ownership of Benefits Management leading to loss of potential benefits	Benefits Management Ownership remains a clear issue at subsequent design review leading to loss of benefit and failure of project objectives.

Appendix C Case study (2): Single task analysis

C.1 FMEA

Table 99: Single task (oven installation): FMEA (part 1)

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Oven installation								
	Time							
		Installation not ready to schedule	7	Delay in earlier activities Define 'entry criteria' to start installation stage	9	Planning experience and operator commitment to complete	2	126
		Installation not ready to schedule	7	Delay in materials, tools or people availability	6	Planning and confirming supply as required to plan	2	84
		Delay to subsequent work	7	Delay in earlier activities causes late start (but actual installation takes the planned duration) Define 'entry criteria' to start installation stage	9	Planning experience and operator commitment to complete	2	126
		Delay to subsequent work	7	Oven installation takes longer than planned	6	Additional resource required on subsequent activities	3	126
		Oven installation 'entry criteria' are not correct	4	Errors on previous work require rework and cause delay – can only be identified when work is complete and ready to commence oven installation.	5	Inspection of previous work to confirm 'entry criteria'	5	100
	Cost							
		Loss of profit – impacting business performance	7	Increase in costs to deliver to contract	6	Fixed price contracts with suppliers	2	84
		Installation not ready – causes cost increase	7	Delay in earlier activities Define 'entry criteria' to start installation stage	9	Planning experience and operator commitment to complete Penalty clause in contract	2	126
		Installation not ready – causes cost increase	7	Delay in materials, tools or people availability	6	Planning and confirming supply as required to plan	2	84
		Delay to subsequent work – causes cost increase	7	Delay in earlier activities causes late start (but actual installation takes the planned duration) Define 'entry criteria' to start installation stage	9	Planning experience and operator commitment to complete Penalty clause in contract	2	126
		Delay to subsequent work – causes cost increase	7	Oven installation takes longer than planned	6	Additional resource required on subsequent activities – may cause a contract penalty	3	126
		Oven installation 'entry criteria' are not correct – causes delay to work start and cost increase	4	Errors on previous work require rework and cause delay – can only be identified when work is complete and ready to commence oven installation.	5	Inspection of previous work to confirm 'entry criteria'	5	100

Table 100: Single task (oven installation): FMEA (part 2)

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
	Scope							
		Design did not fully define the scope	9	Misinterpretation of customer requirement	3	Design review with customer prior to commencing work	1	27
	Quality							
		Incorrect materials supplied	4	Confusion during materials ordering / supply chain	5	Customer review of design solution / specification prior to placing orders	3	60
		Detail design is insufficient for level of tolerance required to achieve acceptable installation	7	Initial planning with customer	3	Customer review of design solution / specification prior to placing orders	3	63
		Detail design is insufficient for level of tolerance required to achieve acceptable installation	7	Detail design planning incorrect	4	Design review	3	84
		Detail design is insufficient for level of tolerance required to achieve acceptable installation	7	Information provided by supplier incorrect or insufficient	4	No process control Work with suppliers to improve supplied information	3	84
	Stakeholders							
		Customer changes requirement	7	Customer community influenced by external events	8	Contract agreement review with customer	3	168
		Disagreement holds up progress	7	Disagreement between prime contractor and customer	4	Contract agreement review with customer	3	84
		Disagreement holds up progress	6	Disagreement between prime contractor and supplier	5	Contract agreement between prime contractor and supplier	3	105
		Suppliers do not meet requirements	8	Inability to meet commitments / contract	4	Contractual penalty	3	96
		Contract labour does not meet requirements	6	Miss-understanding of skill requirement	6	Clear definition of requirement / design review	4	144
	Top Management Support							
		Management prioritises other work	7	Other projects offer more benefit to the business	3	Management acceptance of contract with customer	3	63
	Project Team							
		Key team member not available at oven installation stage	7	Team members are deployed on other projects	5	Workload planning	4	140

Table 101: Single task (oven installation): FMEA (part 3)

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
	Contracts							
		Contract with oven supplier	8	Incorrect oven ordered	3	Review / crosscheck prior to placing order	3	72
		Contract with oven supplier	7	Supplier delivers incorrect oven	4	Review / crosscheck prior to placing order	3	84
		Contract with customer	8	Customer does not recognise contract commitment	4	Customer acceptance of contract with prime contractor	5	160
	Risk							
		Risks mature with no contingency	7	Risk not identified in risk register, or assessed to be insignificant or highly unlikely to mature	3	Risk assessment	3	63
		Completion of installation to agreed schedule / costs	7	Supplier fails to deliver materials as required	5	Contract	3	105
		Completion of installation to agreed schedule / costs	6	Prime contractor fails to organise work	4	Planning	2	48
		Completion of installation to agreed schedule / costs	7	Customer does not allow access to installation site at scheduled time	3	Contract	2	42
	Resources							
		Project schedule delays – cost increase due to additional work to resolve Knock on effect to other projects	6	Suppliers are unavailable when required	4	Resource planning	2	48
		Project schedule delays – cost increase due to additional work to resolve	7	Materials are not available when required	5	Project specification to define material requirements and schedule to identify when required.	3	105
		Project schedule delays – cost increase due to additional work to resolve Knock on effect to other projects	6	Skilled people are unavailable when required	5	Skills matrix & scheduling	3	90
	Project Control / Process							
		Project schedule delays – cost increase due to additional work to resolve – need to introduce new or additional project control Knock on effect to other projects	8	Lack of project control process or no control process	4	Overall process not known or understood	6	192
		Project requires re-planning – causing delay and customer dissatisfaction	6	Project controls to not account for external influences or impact of issues described	4	Stakeholder agreement, via contract, of project plan	2	48
	Project Change							
		Project schedule delays – cost increase due to additional work to resolve – need to introduce new or additional change control process Knock on effect to other projects	8	Change not anticipated	4	No change control process	5	160
		Delay in project impacts subsequent work. Purchased materials no longer required.	7	Customer requirements change	6	Formal agreement by Customer of requirements prior to, or at, contract signing.	2	84

Table 102: Single task (oven installation): FMEA (part 4)

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
	Communications							
		Failure between office and site	5	Scheduling failure to ensure communications between office and site	4	Scheduled communications activities	3	60
		Failure between prime and sub-contractors / suppliers	5	Not defined in contract	4	Scheduled communications activities	3	60
		Failure between prime contractor and customer	6	Prime contractor does not keep customer informed	3	Scheduled communications activities	3	54
	Technology							
		Incorrect solution supplied, or errors require rework	7	Planning software does not integrate all details required for installation	5	Designer experience to ensure acceptable solution	4	140
	Troubleshooting							
		Project schedule delays – cost increase due to additional work to resolve – need to introduce new or additional project control Knock on effect to other projects	5	Issues not identified / lack of troubleshooting activity	3	Limited - management review	3	45
		Late or incorrect product delivery. Lack of supplier support or information	6	Product – Supply chain failures	5	Identify requirements and demand from supply chain prior to commitment to use their products	2	60
		Failure to deliver the required standard of installation to cost or schedule	6	Contractor failures	4	Define delivery criteria at contract agreement	2	48
		Delays and cost increase to installation	5	Customer failures	4	Define delivery criteria at contract agreement	2	40
	Benefits Management							
		Commercial benefits not realised	4	Resolving deviations eliminates benefits	5	Definition of benefits	4	80
		Process benefits delayed	3	Failure to follow process results in schedule or cost increase impacting potential benefits	5	Process review	3	45
	Learning from experience							
		Failure to apply learning to future projects – leading to ongoing level of failure	4	Post installation review does not occur, or fails to identify learning opportunities	4	Post installation review of process to identify overall improvement for future applications	3	48

C.2 WS-TP Analysis

Table 103: Single task (oven installation): WS-TP – Part 1

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Oven installation							
	Project Control / Process	Project schedule delays – cost increase due to additional work to resolve – need to introduce new or additional project control Knock on effect to other projects	Lack of project control process or no control process	Overall process not known or understood	192	Project Control not apparent/ Process for oven installation not clear – contractor requires instruction, or additional information has to be obtained from the manufacturer	Project Control cannot track progress / Process for oven installation cannot proceed because required information is not available – OEM has not provided sufficient information or support
	Stakeholders	Customer changes requirement	Customer community influenced by external events	Contract agreement review with customer	168	Stakeholders changes requirement for oven installation	Stakeholders change of requirements impacts oven installation, causing delays that impact progress of kitchen installation which requires rescheduling of subsequent project.
	Contracts	Contract with customer	Customer does not recognise contract commitment	Customer acceptance of contract with prime contractor	160	Contracts issue takes time to resolve, delaying progress of other tasks	Contracts has to be re-negotiated or causes work to stop and impacting progress of other projects.
	Project Change	Project schedule delays – cost increase due to additional work to resolve – need to introduce new or additional change control process Knock on effect to other projects	Change not anticipated	No change control process	160	No project change process means additional activity is required to manage change issues	Project change impacts oven installation with knock on impact to other activities / projects
	Stakeholders	Contract labour does not meet requirements	Miss-understanding of skill requirement	Clear definition of requirement / design review	144	Stakeholders requirements for oven installation require skill not available within installation contractors – requiring additional skills to be sources	Stakeholders requirements mean oven installation work has to be stopped whilst skill issue is resolved.
	Project Team	Key team member not available at oven installation stage	Team members are deployed on other projects	Workload planning	140	Project Team cannot progress oven installation causing delay until key member is available.	Project Team held up pending oven installation
	Technology	Incorrect solution supplied, or errors require rework	Planning software does not integrate all details required for installation	Designer experience to ensure acceptable solution	140	Incorrect technology for oven installation causes delay whilst rework is carried out.	Technology for oven installation incompatible with other aspects of kitchen installation, requiring on-site re-design leading to delays whilst issues are resolved leading to impact on other projects.
	Time	Installation not ready to schedule	Delay in oven or specific materials. Define 'entry criteria' to start installation stage	Planning experience and operator commitment to complete	126	Oven installation is not ready when scheduled, due to unavailability of specific material required for installation causing delay to actors and materials	Lack of progress on oven installation impacts project progress, causing delay and impact on subsequent projects.
	Time	Delay to subsequent work	Delay in earlier activities causes late start (but actual installation takes the planned duration) Define 'entry criteria' to start installation stage	Planning experience and operator commitment to complete	126	Oven installation is not ready when scheduled, causing delay to actors and materials	Lack of progress on oven installation impacts project progress, causing delay and impact on subsequent projects.
	Time	Delay to subsequent work	Oven installation takes longer than planned	Additional resource required on subsequent activities	126	Extended time scales for oven installation impacts project schedule	Lack of progress on oven installation impacts project progress, causing delay and impact on subsequent projects.

Table 104: Single task (oven installation): WS-TP (Part 2)

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
	Cost	Installation not ready – causes cost increase	Delay in earlier activities Define 'entry criteria' to start installation stage	Planning experience and operator commitment to complete Penalty clause in contract	126	Oven installation is not ready when scheduled, due to unavailability of specific material required for installation causing cost increase to actors and materials	Lack of progress on oven installation impacts project progress, causing cost increase and impact on subsequent projects.
	Cost	Delay to subsequent work – causes cost increase	Delay in earlier activities causes late start (but actual installation takes the planned duration) Define 'entry criteria' to start installation stage	Planning experience and operator commitment to complete Penalty clause in contract	126	Oven installation is not ready when scheduled, causing cost increase to actors and materials	Lack of progress on oven installation impacts project progress, causing cost increase and impact on subsequent projects.
	Cost	Delay to subsequent work – causes cost increase	Oven installation takes longer than planned	Additional resource required on subsequent activities – may cause a contract penalty	126	Extended time scales for oven installation impacts project schedule	Lack of progress on oven installation impacts project progress, causing cost increase and impact on subsequent projects.
	Stakeholders	Disagreement holds up progress	Disagreement between prime contractor and supplier	Contract agreement between prime contractor and supplier	105	Stakeholders disagreement for oven installation causes delays that hold progress, cause cost increase and impact other work	Stakeholders disagreement for oven installation causes delays that hold progress, cause cost increase and impact other work
	Risk	Completion of installation to agreed schedule / costs	Supplier fails to deliver materials as required	Contract	105	Risk mature causing delay to oven installation task	Oven installation task is put on hold whilst issues are resolved, leading to delay and impact on other activities.
	Resources	Project schedule delays – cost increase due to additional work to resolve	Materials are not available when required	Project specification to define material requirements and schedule to identify when required.	105	Resource failure delays oven installation	Oven installation is put on hold whilst alternative resources are obtained
	Cost	Oven installation 'entry criteria' are not correct – causes delay to work start and cost increase	Errors on previous work require rework and cause delay – can only be identified when work is complete and ready to commence oven installation.	Inspection of previous work to confirm 'entry criteria'	100	Incorrect predecessor to oven installation causes cost increase whilst rework is carried out.	Progress on oven installation impacts project progress, causing cost increase and impact on subsequent projects.
	Time	Oven installation 'entry criteria' are not correct	Errors on previous work require rework and cause delay – can only be identified when work is complete and ready to commence oven installation.	Inspection of previous work to confirm 'entry criteria'	100	Incorrect predecessor to oven installation causes delay whilst rework is carried out.	Lack of progress on oven installation impacts project progress, causing delay and impact on subsequent projects.

Appendix D Case study (3): Facility Development

D.1 Customer requirements

D.1.1 FMEA

Table 105: Facility Development: Customer requirements: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Customer requirements								
	Top Management Support	How do sub-contractors deliver against customer requirements?	7	Top management don't include contractors in project development / progress	6	Contract	4	168
	Stakeholders	Customer stakeholders incorrectly identified.	7	Failure to understand how the organisation of stakeholders will function	6	Project plan and stakeholder management	4	168
	Benefits Management	Loss of contract	7	Failure to identify contract benefits and link them to requirements	5	None	4	140
	Stakeholders	Customer stakeholders incorrectly identified.	7	Stakeholders not fully identified	5	Detail scope review to capture additional requirements	4	140
	Cost	Business makes a loss on the project	6	Budget tracking does not anticipate overspend	4	Budget tracked against spend plan and change control	5	120
	Scope	Unable to deliver to customer specification	7	Planning that fits timescales	4	Review of plan Challenge potential to meet timescales	4	112
	Contracts	Failure of supplier contracts	7	Supplier contract is not aligned to project requirements	4	Contract review to meet regulations within contract	4	112
	Project Control / Process	Project not under control	7	Project management techniques / plan review	4	Project controls Process control plan	4	112
	Top Management Support	Schedule delay and cost increase	6	Lack of priority on project	6	Top management are responsible for delivering the contract	3	108
	Project Team	Resources unavailable to the project	7	Demand from other projects prioritises resource deployment	5	Matching requirements and resource	3	105

D.1.2 WS-TP analysis

Table 106: Facility Development: Customer requirements: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Customer requirements							
	Top Management Support	How do sub-contractors deliver against customer requirements?	Top management don't include contractors in project development / progress	Contract	168	Contractors query or don't respond to planned or agreed activities. Action is required to prompt contractors to progress or deliver planned actions.	Expected deliveries don't occur to planed criteria.
	Stakeholders	Customer stakeholders incorrectly identified.	Failure to understand how the organisation of stakeholders will function	Project plan and stakeholder management	168	Stakeholders query or don't respond to planned or agreed activities. Action is required to prompt stakeholders to progress or deliver planned actions.	Expected deliveries don't occur to planed criteria.
	Benefits Management	Loss of contract	Failure to identify contract benefits and link them to requirements	None	140	Contract requirements are not clearly identified. Contract review needs to be revisited.	Contract review identifies 'new' requirements not previously included in project plan.
	Stakeholders	Customer stakeholders incorrectly identified.	Stakeholders not fully identified	Detail scope review to capture additional requirements	140	Delays or confusion occurs when dealing with customer stakeholders. Points of contact change	It becomes necessary to escalate issues up the customers management structure
	Cost	Business makes a loss on the project	Budget tracking does not anticipate overspend	Budget tracked against spend plan and change control	120	Budget tracking (e.g. Earned Value Management) indicates overspend	Contract required funding review
	Scope	Unable to deliver to customer specification	Planning that fits timescales	Review of plan Challenge potential to meet timescales	112	Basic criteria to meet customer specification need to be revisited	Customer design review identifies elements of the specification that have not been met.
	Contracts	Failure of supplier contracts	Supplier contract is not aligned to project requirements	Contract review to meet regulations within contract	112	Supplier does not respond to request for progress report	Supplier does not deliver to agreed criteria
	Project Control / Process	Project not under control	Project management techniques / plan review	Project controls Process control plan	112	Project review meetings generate more questions / unresolved issues than they resolve	Management review / formal design review is postponed to allow issues to be resolved
	Top Management Support	Schedule delay and cost increase	Lack of priority on project	Top management are responsible for delivering the contract	108	Top management support is not available when requested by project manager	Project manager needs to take corrective action without top management agreement leading to further re-work when postponed top management review occurs
	Project Team	Resources unavailable to the project	Demand from other projects prioritises resource deployment	Matching requirements and resource	105	Task activities delayed because other projects are given higher priority to common resource	Despite escalating issues, resource is directed elsewhere resulting in a clear failure to complete work, with consequent schedule of cost impact

D.2 Fixture design and manufacture

D.2.1 FMEA

Table 107: Facility Development: Fixture design and manufacture: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Fixture design and manufacture								
	Project Team	Failure of team to deliver	7	Project team haven't fully grasped requirements – uncertainties in workload and completion	6	Scope and requirements communication to project team – understanding of risks	5	210
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	8	Lack of priority from top management for specific project	5	Not communicated by top management	5	200
	Project Change	Delivered product does not meet requirements	8	Group members avoid raising change requirements	5	Management review	5	200
	Time	Late delivery of tasks impacts overall project delivery	8	Insufficient schedule contingency to deal with uncertainty	6	Schedule fixture delivery planning as part of bid process	4	192
	Project change	Uncertainties are not resolved leading to delays	6	Change process needs to recognise and resolve uncertainty	6	Management review	5	180
	Cost	Failure of fixture budget	7	Sub-contract costs exceed initial estimates or prime contract	5	Contract agreement on budget and contingency	5	175
	Cost	Late delivery of tasks impacts overall project budget	7	Insufficient budget contingency to deal with uncertainty	5	Budget planning as part of bid process	5	175
	Quality	Failure to deliver to legislative requirements – fixtures require rework	7	Failure to recognise applicable legislation	5	Knowledge of legislation and relevant experience Formal review of legislation embodied in requirements	5	175
	Quality	Wrong quality specification	7	Required quality standard not applied	5	Definition of Quality Standards and Procedures	5	175
	Communications	All issues around the project are likely to have an aspect of communications	7	Failure to communicate between actors	5	Regular communications meetings	5	175

D.2.2 WS-TP analysis

Table 108: Facility Development: Fixture design and manufacture: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Fixture design and manufacture							
	Project Team	Failure of team to deliver	Project team haven't fully grasped requirements – uncertainties in workload and completion	Scope and requirements communication to project team – understanding of risks	210	Development of fixture deign and manufacture activities requires multiple iterations. Design review to engage supplier generates significant actions or rework	Design review needs to be repeated
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	Lack of priority from top management for specific project	Not communicated by top management	200	It becomes apparent that contractors are not prioritising tasks	Need to use top management to ensure contractor meets requirements
	Project Change	Delivered product does not meet requirements	Group members avoid raising change requirements	Management review	200	Design review identifies issues that do not meet requirements	It becomes clear that need for changes in requirements were recognised but not acted on.
	Time	Late delivery of tasks impacts overall project delivery	Insufficient schedule contingency to deal with uncertainty	Schedule fixture delivery planning as part of bid process	192	Task progress reviews are delayed	A task milestone is not achieved
	Project change	Uncertainties are not resolved leading to delays	Change process needs to recognise and resolve uncertainty	Management review	180	Change proposals remain un-actioned	Failure to implement change proposal leads to rework
	Cost	Failure of fixture budget	Sub-contract costs exceed initial estimates or prime contract	Contract agreement on budget and contingency	175	Sub-contractors raise issues around costs and schedule	A task milestone is not achieved
	Cost	Late delivery of tasks impacts overall project budget	Insufficient budget contingency to deal with uncertainty	Budget planning as part of bid process	175	A task milestone is not achieved	Late delivery impacts subsequent tasks – particularly if on the critical path
	Quality	Failure to deliver to legislative requirements – fixtures require rework	Failure to recognise applicable legislation	Knowledge of legislation and relevant experience Formal review of legislation embodied in requirements	175	Need to review legislation	Need to revise design solution to meet legislation
	Quality	Wrong quality specification	Required quality standard not applied	Definition of Quality Standards and Procedures	175	Need to review quality specification	Need to revise design solution to meet quality specification
	Communications	All issues around the project are likely to have an aspect of communications	Failure to communicate between actors	Regular communications meetings	175	Issues remain despite communications	Additional 'emergency' communications are required to ensure issues are understood / resolved

D.3 CNC programming

D.3.1 FMEA

Table 109: Facility Development: CNC programming: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
CNC Programming								
	Quality	Failure to deliver to legislative requirements	8	Failure to recognise applicable legislation	6	Knowledge of legislation and relevant experience Formal review of legislation embodied in requirements	5	240
	Top Management Support	Sub- contractor management don't prioritise project tasks leading to delay or project failure	8	Lack of priority from top management for specific CNC programming activity	5	Not communicated by top management	5	200
	Project Change	Delivered product does not meet requirements	8	Group members avoid raising change requirements	5	Management review	5	200
	Top Management Support	Top management focus on other priorities	6	Top management lack understanding of project leading to uncertainty of its completion	6	Bid process and Top management approval of project plan	5	180
	Communications	All issues around the project are likely to have an aspect of communications	7	Failure to communicate between actors	5	Regular communications meetings	5	175
	Quality	Failure to deliver to customer requirements	6	Failure to analyse customer requirements and associate with skills of personnel	5	Design review including customer agreement	5	150
	Time	Failure to provision for CNC programing within task schedule impacts overall project delivery	6	Underestimating CNC programming time	6	Project plan	4	144
	Stakeholders	Priority of resources within partner organisations	6	Facilities and equipment may be prioritised to other tasks	4	Agreement between partners of resource and equipment commitment required. Detail progress monitoring and communication with partners to ensure commitments are being met.	6	144
	Contracts	Lack of communication leads to inappropriate contracts and problems to deliver the CNC programming aspect of the project	8	Understanding project requirements and structuring distribution between prime and sub-contract	6	Contract review	3	144
	Stakeholders	Lack of communication leads to conflict between stakeholders	7	Understanding the project structure across stakeholders	5	Contract	4	140

D.3.2 WS-TP analysis

Table 110: Facility Development: CNC programming: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
CNC Programming							
	Quality	Failure to deliver to legislative requirements	Failure to recognise applicable legislation	Knowledge of legislation and relevant experience Formal review of legislation embodied in requirements	240	Define design code for programming	Code has to be re-written
	Top Management Support	Sub-contractor management don't prioritise project tasks leading to delay or project failure	Lack of priority from top management for specific CNC programming activity	Not communicated by top management	200	Scope to deliver code is ill defined	Schedule revision whilst corrective action is taken
	Project Change	Delivered product does not meet requirements	Group members avoid raising change requirements	Management review	200	"its all OK"	"Need more time"
	Top Management Support	Top management focus on other priorities	Top management lack understanding of project leading to uncertainty of its completion	Bid process and Top management approval of project plan	180	Project scope not defined	Project review focuses on programming and resolving issues
	Communications	All issues around the project are likely to have an aspect of communications	Failure to communicate between actors	Regular communications meetings	175	Project scope not defined	Project review focuses on programming and resolving issues
	Quality	Failure to deliver to customer requirements	Failure to analyse customer requirements and associate with skills of personnel	Design review including customer agreement	150	Revisit requirements	Review with customer
	Time	Failure to provision for CNC programing within task schedule impacts overall project delivery	Underestimating CNC programming time	Project plan	144	Revisit requirements	Reschedule
	Stakeholders	Priority of resources within partner organisations	Facilities and equipment may be prioritised to other tasks	Agreement between partners of resource and equipment commitment required. Detail progress monitoring and communication with partners to ensure commitments are being met.	144	Delay on resource	Reschedule
	Contracts	Lack of communication leads to inappropriate contracts and problems to deliver the CNC programming aspect of the project	Understanding project requirements and structuring distribution between prime and sub-contract	Contract review	144	Initial delivery requires rework	Revise contract
	Stakeholders	Lack of communication leads to conflict between stakeholders	Understanding the project structure across stakeholders	Contract	140	Stakeholder review	Revise contract

D.4 Lifting and Handling

D.4.1 FMEA

Table 111: Facility Development: Lifting and Handling: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Task 5 – Materials logistics – lifting and handling								
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	8	Lack of priority from top management for specific project	5	Not communicated by top management	5	200
	Project Change	Delivered product does not meet requirements	8	Group members avoid raising change requirements	5	Management review	5	200
	Time	Failure to provision lifting and handling facilities within task schedule impacts overall project delivery	8	Sub-contractor is not contracted to meet task or project schedule	6	Contract	4	192
	Stakeholders	*"This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required"* (Coley 2008)	6	*"It was apparent that some partners were not aware of the level of commitment that was required of them."* (Coley 2008)	6	Top management commitment to support project	5	180
	Communications	All issues around the project are likely to have an aspect of communications	7	Failure to communicate between actors	5	Regular communications meetings	5	175
	Project Control / Process	No commitment to any specific decision – leading to lack of direction and extended time period before any solution is accepted	7	*"Decisions that are made early on are extremely likely to change. This made decision making difficult"* (Coley 2008)	6	Problem definition & specification	4	168
	Stakeholders	Failure to deliver	8	Underlying stakeholder issues not identified	4	Planning and Contingency	5	160
	Project Control / Process	Inconsistent project controls do not raise issues	6	Project control / process does not accommodate uncertainty – insufficient contingency	5	Problem definition & specification And resource allocation	5	150
	Stakeholders	Priority of resources within partner organisations	6	Facilities and equipment may be prioritised to other tasks	4	Agreement between partners of resource and equipment commitment required. Detail progress monitoring and communication with partners to ensure commitments are being met.	6	144
	Top Management Support	Top management focus on other priorities	8	Top management lack understanding of project leading to uncertainty of its completion	6	Bid process and Top management approval of project plan	3	144

D.4.2 Lifting and Handling – WS and TP

Table 112: Facility Development: Lifting and Handling: WS-TP analysis

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Task 5 – Materials logistics – lifting and handling							
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	Lack of priority from top management for specific project	Not communicated by top management	200	Delay on activities due to alternative priorities.	Project activities rescheduled
	Project Change	Delivered product does not meet requirements	Group members avoid raising change requirements	Management review	200	Early design review identifies failure to meet requirements	Requirements failure remains unresolved at subsequent design review
	Time	Failure to provision lifting and handling facilities within task schedule impacts overall project delivery	Sub-contractor is not contracted to meet task or project schedule	Contract	192	Mandated sub-contractor cannot offer a solution to meet task requirements	Alternative sub-contractor cannot offer a solution to meet task requirements
	Stakeholders	*"This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required"* (Coley 2008)	*"It was apparent that some partners were not aware of the level of commitment that was required of them."* (Coley 2008)	Top management commitment to support project	180	Top management prioritise other actions with key stakeholders	Change in stakeholder
	Communications	All issues around the project are likely to have an aspect of communications	Failure to communicate between actors	Regular communications meetings	175	Known issues are not disseminated	Communications meetings delayed or rescheduled
	Project Control / Process	No commitment to any specific decision – leading to lack of direction and extended time period before any solution is accepted	*"Decisions that are made early on are extremely likely to change. This made decision making difficult"* (Coley 2008)	Problem definition & specification	168	Actions placed at design reviews	Actions remain unresolved, impacting project progress
	Stakeholders	Failure to deliver	Underlying stakeholder issues not identified	Planning and Contingency	160	Stakeholder does not offer evidence of progress	Milestone delivery is delayed
	Project Control / Process	Inconsistent project controls do not raise issues	Project control / process does not accommodate uncertainty – insufficient contingency	Problem definition & specification And resource allocation	150	Problems identified by the project control process remain unresolved.	Project control process identifies re-work requiring change to baseline plan
	Stakeholders	Priority of resources within partner organisations	Facilities and equipment may be prioritised to other tasks	Agreement between partners of resource and equipment commitment required. Detail progress monitoring and communication with partners to ensure commitments are being met.	144	Stakeholders apply resources to other activities	Request for resource and priority review are declined
	Top Management Support	Top management focus on other priorities	Top management lack understanding of project leading to uncertainty of its completion	Bid process and Top management approval of project plan	144	Decisions need to be revisited	Incorrect decision made, leading to rework

D.5 Materials logistics: supply chain

D.5.1 FMEA

Table 113: Facility Development: Manufacturing logistics: supply chain: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Materials Logistics – Supply Chain								
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	8	Lack of priority from top management for specific project	5	Not communicated by top management	5	200
	Project Change	Delivered product does not meet requirements	8	Group members avoid raising change requirements	5	Management review	5	200
	Project Change	Delivered product does not meet requirements	8	Change process needs to recognise and resolve uncertainty	6	Change control process	4	192
	Stakeholders	*"This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required"* (Coley 2008)	6	*"It was apparent that some partners were not aware of the level of commitment that was required of them."* (Coley 2008)	6	Top management commitment to support project	5	180
	Communications	All issues around the project are likely to have an aspect of communications	7	Failure to communicate between actors	5	Regular communications meetings	5	175
	Stakeholders	*"This meant that those working full time were constantly waiting for work from other members of the team before they could continue. This caused a sense of frustration"* (Coley 2008)	6	*"Some actors worked full time on the project whilst other actors worked part time."* (Coley 2008)	5	Top management commitment to support project progress	5	150
	Project Team	Failure of team to deliver	6	Project team haven't fully grasped requirements – uncertainties in workload and completion	5	Scope and requirements communication to project team – understanding of risks	5	150
	Stakeholders	Priority of resources within partner organisations	6	Facilities and equipment may be prioritised to other tasks	4	Agreement between partners of resource and equipment commitment required. Detail progress monitoring and communication with partners to ensure commitments are being met.	6	144
	Stakeholders	Failure to deliver	6	Underlying stakeholder issues not identified	6	Planning and Contingency	4	144
	Contracts	Lack of communication leads to inappropriate contracts and problems to deliver the project	8	Understanding project requirements and structuring distribution between prime and sub-contract	6	Contract review	3	144

D.5.2 WS-TP analysis

Table 114: Facility Development: Manufacturing logistics: supply chain: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Materials Logistics – Supply Chain							
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	Lack of priority from top management for specific project	Not communicated by top management	200	Issues in supply chain remain unresolved at early planning / progress reviews	Issues demand rescheduling
	Project Change	Delivered product does not meet requirements	Group members avoid raising change requirements	Management review	200	Supply chain does not respond to change requests to meet requirements	Supply chain requires re-work to resolve change issue
	Project Change	Delivered product does not meet requirements	Change process needs to recognise and resolve uncertainty	Change control process	192	Supply chain does not respond to change requests to meet requirements	Supply chain delivers incorrect items
	Stakeholders	*"This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required"* (Coley 2008)	*"It was apparent that some partners were not aware of the level of commitment that was required of them."* (Coley 2008)	Top management commitment to support project	180	Supply chain does not apply the needed priority	Top management involvement is required to bring stakeholders up to the required level of commitment to deliver the project
	Communications	All issues around the project are likely to have an aspect of communications	Failure to communicate between actors	Regular communications meetings	175	Supply chain not involved in communications – or do not attend reviews when invited	Communication failure leads to incorrect delivery from supply chain
	Stakeholders	*"This meant that those working full time were constantly waiting for work from other members of the team before they could continue. This caused a sense of frustration"* (Coley 2008)	*"Some actors worked full time on the project whilst other actors worked part time."* (Coley 2008)	Top management commitment to support project progress	150	Prime contractor personnel have to chase up supply chain for information / deliveries	Supply chain continues to place low priority on tasks – leading to impact on task progress, particularly critical path tasks
	Project Team	Failure of team to deliver	Project team haven't fully grasped requirements – uncertainties in workload and completion	Scope and requirements communication to project team – understanding of risks	150	Revision of actions with the supply chain	Supply chain fails to deliver on defined requirements
	Stakeholders	Priority of resources within partner organisations	Facilities and equipment may be prioritised to other tasks	Agreement between partners of resource and equipment commitment required. Detail progress monitoring and communication with partners to ensure commitments are being met.	144	Facilities not available to task plan	Impact scheduling
	Stakeholders	Failure to deliver	Underlying stakeholder issues not identified	Planning and Contingency	144	Impacts schedule	Impacts subsequent tasks
	Contracts	Lack of communication leads to inappropriate contracts and problems to deliver the project	Understanding project requirements and structuring distribution between prime and sub-contract	Contract review	144	Sub-contractors invoke contract clauses	Contract has to be re-negotiated

D.6 Manufacturing Process Documentation

D.6.1 Manufacturing Process Document: FMEA

Table 115: Facility Development: Manufacturing process documentation: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Manufacturing Support Documentation								
	Quality	Failure to deliver to legislative requirements	8	Failure to recognise applicable legislation	6	Knowledge of legislation and relevant experience Formal review of legislation embodied in requirements	5	240
	Time	Failure to provision fixtures within task schedule impacts manufacturing support documentation approval and overall project delivery	7	Sub-contractor manufacturing is not scheduled to meet task or project schedule causing documentation mismatch	6	Project plan and reaction to changes in requirements and subsequent communication with sub-contractor	5	210
	Project Control / Process	Activities are not progressed unless project control demands	7	Project control / process does not accommodate uncertainty – insufficient contingency	6	Senior management review	5	210
	Project Change	Delivered product does not meet requirements	8	Group members avoid raising change requirements	5	Management review	5	200
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	8	Lack of priority from top management for specific project	5	Not communicated by top management	5	200
	Stakeholders	Failure to deliver	8	Underlying stakeholder issues not identified	6	Planning and Contingency	4	192
	Communications	All issues around the project are likely to have an aspect of communications	7	Failure to communicate between actors	5	Regular communications meetings	5	175
	Time	Support documentation not produced / approved in line with changes in plan – leading to delay in initial manufacture	7	Fixture manufacturing capacity out of sequence to changes in project schedule leads to out of sequence support documentation being produced	6	Project plan and reaction to changes in requirements	4	168
	Risk	Multiple minor risks mature impacting task / project performance	7	Scope of risk assessment is limited leading to uncertainty and lack of contingency	6	Risk register / management / Review	4	168
	Scope	Fixtures unavailable to meet schedule and do not have required support documentation	6	Scope creep - Customer requires further constraints to be met	6	Project plan and schedule to deliver tooling and support documentation	4	144

D.6.2 Manufacturing Process Documentation: WS-TP Analysis

Table 116: Facility Development: Manufacturing process documentation: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Manufacturing Support Documentation							
	Quality	Failure to deliver to legislative requirements	Failure to recognise applicable legislation	Knowledge of legislation and relevant experience Formal review of legislation embodied in requirements	240	Need to review legislation	Need to revise design solution to meet legislation – documentation needs to be revised / reissued
	Time	Failure to provision fixtures within task schedule impacts manufacturing support documentation approval and overall project delivery	Sub-contractor manufacturing is not scheduled to meet task or project schedule causing documentation mismatch	Project plan and reaction to changes in requirements and subsequent communication with sub-contractor	210	Documentation delayed waiting on fixtures	Documentation is not agreed with stakeholders / customer and task milestones are missed
	Project Control / Process	Activities are not progressed unless project control demands	Project control / process does not accommodate uncertainty – insufficient contingency	Senior management review	210	Documentation is delayed due to focus on other aspects of the project	Design review identifies lack of progress
	Project Change	Delivered product does not meet requirements	Group members avoid raising change requirements	Management review	200	Documentation requires review / update to incorporate changes	Management review identifies changes that need to be included
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	Lack of priority from top management for specific project	Not communicated by top management	200	Top management redeploys personnel required to compile documentation	
	Stakeholders	Failure to deliver	Underlying stakeholder issues not identified	Planning and Contingency	192	Stakeholders do not provide required support to documentation writing process	Documentation has to be revised following stakeholder / customer review
	Communications	All issues around the project are likely to have an aspect of communications	Failure to communicate between actors	Regular communications meetings	175	Issues impacting documentation are not communicated	Documentation has to be revised following stakeholder / customer review
	Time	Support documentation not produced / approved in line with changes in plan – leading to delay in initial manufacture	Fixture manufacturing capacity out of sequence to changes in project schedule leads to out of sequence support documentation being produced	Project plan and reaction to changes in requirements	168	Schedule to deliver documentation delayed	Impact on subsequent tasks, particularly on critical path
	Risk	Multiple minor risks mature impacting task / project performance	Scope of risk assessment is limited leading to uncertainty and lack of contingency	Risk register / management / Review	168	Risks mature and impact progress on documentation	Risks mature and force a rescheduling of documentation activities
	Scope	Fixtures unavailable to meet schedule and do not have required support documentation	Scope creep - Customer requires further constraints to be met	Project plan and schedule to deliver tooling and support documentation	144	Need to chase up suppliers to obtain required documentation	Documentation has to be revised following stakeholder / customer review

D.7 Short Term Production Delivery

D.7.1 FMEA

Table 117: Facility Development: Short term production delivery: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Short Term Production Delivery								
	Quality	Failure to deliver to legislative requirements	8	Failure to recognise applicable legislation	6	Knowledge of legislation and relevant experience Formal review of legislation embodied in requirements	5	240
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	8	Lack of priority from top management for specific project	5	Not communicated by top management	5	200
	Project Change	Delivered product does not meet requirements	8	Group members avoid raising change requirements	5	Management review	5	200
	Stakeholders	*"This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required"* (Coley 2008)	6	*"It was apparent that some partners were not aware of the level of commitment that was required of them."* (Coley 2008)	6	Top management commitment to support project	5	180
	Communications	All issues around the project are likely to have an aspect of communications	7	Failure to communicate between actors	5	Regular communications meetings	5	175
	Stakeholders	*"This meant that those working full time were constantly waiting for work from other members of the team before they could continue. This caused a sense of frustration"* (Coley 2008)	6	*"Some actors worked full time on the project whilst other actors worked part time."* (Coley 2008)	5	Top management commitment to support project progress	5	150
	Contracts	Failure of task to meet contract requirements causing rework that impacts overall project	6	Contract is not clear – leading to uncertainty	5	Contract review	5	150
	Stakeholders	Priority of resources within partner organisations	6	Facilities and equipment may be prioritised to other tasks	4	Agreement between partners of resource and equipment commitment required. Detail progress monitoring and communication with partners to ensure commitments are being met.	6	144
	Contracts	Lack of communication leads to inappropriate contracts and problems to deliver the project	8	Understanding project requirements and structuring distribution between prime and sub-contract	6	Contract review	3	144
	Communications	*"This meant that frequently decisions made by one partner were not communicated with the rest of the team. This often resulted in a partner working on part of the design using the wrong dimensions for example"* (Coley 2008)	6	*"It appeared that some team members were unaware of the importance and need to communicate information, particularly when making design decisions."* (Coley 2008)	6	Need to maintain communication between team members	4	144

D.7.2 WS-TP analysis

Table 118: Facility Development: Short term production delivery: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Short Term Production Delivery							
	Quality	Failure to deliver to legislative requirements	Failure to recognise applicable legislation	Knowledge of legislation and relevant experience Formal review of legislation embodied in requirements	240	Need to review legislation	Need to revise design solution to meet legislation
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	Lack of priority from top management for specific project	Not communicated by top management	200	Early stage production learning curve is not recognised	Tasks need to be reschedule to allow early stage learning curve
	Project Change	Delivered product does not meet requirements	Group members avoid raising change requirements	Management review	200	Requirements conformance requires additional activities	Implementation of changes to requirements
	Stakeholders	*"This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required"* (Coley 2008)	*"It was apparent that some partners were not aware of the level of commitment that was required of them."* (Coley 2008)	Top management commitment to support project	180	Impacts progress of activities required to support initial production	Need to rework materials to achieve initial production
	Communications	All issues around the project are likely to have an aspect of communications	Failure to communicate between actors	Regular communications meetings	175	Short term production details not communicated	Impacts short term production deliveries
	Stakeholders	*"This meant that those working full time were constantly waiting for work from other members of the team before they could continue. This caused a sense of frustration"* (Coley 2008)	*"Some actors worked full time on the project whilst other actors worked part time."* (Coley 2008)	Top management commitment to support project progress	150	Supply chain support to short term production impacts progress	Impacts short term production deliveries
	Contracts	Failure of task to meet contract requirements causing rework that impacts overall project	Contract is not clear – leading to uncertainty	Contract review	150	Contract review impacts plan to meet short term production requirements	Revision of contract
	Stakeholders	Priority of resources within partner organisations	Facilities and equipment may be prioritised to other tasks	Agreement between partners of resource and equipment commitment required. Detail progress monitoring and communication with partners to ensure commitments are being met.	144	Stakeholders do not provide support to short term production	Causes failure of initial production item or impacts short term production deliveries
	Contracts	Lack of communication leads to inappropriate contracts and problems to deliver the project	Understanding project requirements and structuring distribution between prime and sub-contract	Contract review	144	Impacts progress of activities to achieve initial production	Causes failure of initial production item or impacts short term production deliveries
	Communications	*"This meant that frequently decisions made by one partner were not communicated with the rest of the team. This often resulted in a partner working on part of the design using the wrong dimensions for example"* (Coley 2008)	*"It appeared that some team members were unaware of the importance and need to communicate information, particularly when making design decisions."* (Coley 2008)	Need to maintain communication between team members	144	Communications failures impact progress of activities to achieve initial production	Causes failure of initial production item or impacts short term production deliveries

Appendix E Case study (4): Research Project (part 1): Demonstration

E.1 – Demonstration

E.1.1 FMEA

Table 119: Research project (part 1) demonstration: repeatability: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	SEV	Potential Cause(s) / Mechanism(s) of Failure	OSS	Current Process Controls	DET	RPN
Repeatability								
	Troubleshooting	Potential problems are not identified and resolved leading to further issues	6	Across the whole project	4	None	10	240
	Top Management Support	Task progress is delayed – impacting overall project delivery potentially leading to failure	7	Sub-contractors top management focus on higher value work – delivery to task requirements becomes 'last minute'	6	Sub-contractor contract / Trials plan	5	210
	Project Change	Delivered product does not meet requirements	8	Group members avoid raising change requirements	5	Management review	5	200
	Benefits Management	Not realised	5	Broader application to product manufacture	4	None	10	200
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	8	Lack of priority from top management for specific project	5	Not communicated by top management	5	200
	Stakeholders	Friction between partners makes the trials difficult	6	some partners were not aware of the level of commitment required	6	Top management commitment to support project	5	180
	Communications	All issues around the project are likely to have an aspect of communications	7	Failure to communicate between actors	5	Regular communications meetings	5	175
	Project Control / Process	Project deviates from plan – but is not identified by project controls until there is a significant issue	7	Project control / process does not accommodate uncertainty – insufficient contingency	5	Contingency plan / management reserve	5	175
	Learning from experience	Failure to identify lessons from the project organisation	5	Lack of improved development process for future tasks	3	None	10	150
	Contracts	Lack of communication leads to inappropriate contracts and problems to deliver the project	8	Understanding project requirements and structuring distribution between prime and sub-contract	6	Contract review	3	144

E.1.2 WS-TP analysis

Table 120: Research project (part 1) demonstration: repeatability: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Repeatability							
	Troubleshooting	Potential problems are not identified and resolved leading to further issues	Across the whole project	None	240	Issues remain ongoing and unresolved at review meetings	A known problem impacts task delivery – particularly if on the critical path.
	Top Management Support	Task progress is delayed – impacting overall project delivery potentially leading to failure	Sub-contractors top management focus on higher value work – delivery to task requirements becomes 'last minute'	Sub-contractor contract / Trials plan	210	Maintaining task progress is challenging – needing top management support. Continuous need to chase this support impacts task progress.	Progress of task is held waiting top management support and impacts project progress.
	Project Change	Delivered product does not meet requirements	Group members avoid raising change requirements	Management review	200	Complexity of a change issue emerges and increases over several review meetings	Progress of the change issue impacts task delivery – particularly if on the critical path.
	Benefits Management	Not realised	Broader occurrence within product manufacture	None	200	Limited action taken to identify potential benefits or exploit their application	Focus on delivering task objectives
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	Lack of priority from top management for specific project	Not communicated by top management	200	Contractors are not prepared for review meetings	Contractor fails to attend review meeting – particularly if responsible for critical actions
	Stakeholders	Friction between partners makes the trials difficult	some partners were not aware of the level of commitment required	Top management commitment to support project	180	Issues between stakeholders (rather than project focus) become the main topic of the review.	One stakeholder does not attend review due to conflict with another stakeholder
	Communications	All issues around the project are likely to have an aspect of communications	Failure to communicate between actors	Regular communications meetings	175	Communications on known issues are delayed.	Failure to communicate leads to escalation of issues and impacts contract
	Project Control / Process	Project deviates from plan – but is not identified by project controls until there is a significant issue	Project control / process does not accommodate uncertainty – insufficient contingency	Contingency plan / management reserve	175	Early review indicates all tasks on plan	Later review shows tasks could not have been to plan at the earlier review
	Learning from experience	Failure to identify lessons from the project organisation	Lack of improved development process for future tasks	None	150	'Typical' problem, known from previous projects, recurs	Known solution is not efficiently applied.
	Contracts	Lack of communication leads to inappropriate contracts and problems to deliver the project	Understanding project requirements and structuring distribution between prime and sub-contract	Contract review	144	Design review identifies contract issues and prompts contract review.	Contract is revised

E.2 – Requirements

E.2.1 FMEA

Table 121: Research project (part 1) demonstration: requirements: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
requirements								
	Benefits Management	Failure to complete task leading to loss of contract	6	Failure to identify contract benefits and link them to requirements	3	None	10	180
	Project Team	Lack of structure leads to project failure	7	Will stakeholders focus on other priorities?	6	Stakeholders have a vested interest	4	168
	Risk	Risks mature without contingency plan	7	Risk analysis across the task not conducted	6	Risk review	4	168
	Learning from experience	Experience does not translate - delay caused by time spent on benefits management earlier in task	4	How does initial analysis translate to full analysis later in the project?	4	None	10	160
	Risk	Task delivery becomes more complex	7	Multiple minor risks mature	7	Risk register and product / process FMEA	3	147
	Quality	Deliverables are not accepted by customer	7	Insufficient evidence of quality procedures	4	Alignment of existing quality procedures to project requirements, identify gaps and introduce new procedures	5	140
	Stakeholders	Incorrect stakeholders involved	7	Fully defined	5	Stakeholder review at bid stage	4	140
	Project Team	Diverging interests cause project team to fragment – slowing progress	7	Will project teams have common interests	6	Selection process for contractors and suppliers	3	126
	Stakeholders	Customer stakeholders incorrectly identified.	5	Failure to understand how the organisation of stakeholders will function	6	Project plan and stakeholder management	4	120
	Contracts	Failure of supplier contracts	6	Supplier contract is not aligned to project requirements	5	Contract review to meet regulations within contract	4	120

E.2.2 WS-TP analysis

Table 122: Research project (part 1) demonstration: requirements: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Requirements							
	Benefits Management	Failure to complete task leading to loss of contract	Failure to identify contract benefits and link them to requirements	None	180	Clear definition and confirmation of requirements – leading to achieving benefits – is not achieved	Early design review identifies corrective actions applicable to requirements, reducing potential benefits
	Project Team	Lack of structure leads to project failure	Will stakeholders focus on other priorities?	Stakeholders have a vested interest	168	Project team does not have skill set to deliver requirements	Project team has to be restructured – requiring time to recruit and appoint staff and disrupting progress to deliver the requirements of the project.
	Risk	Risks mature without contingency plan	Risk analysis across the task not conducted	Risk review	168	Requirements related risk matures and diverts resource to defining and implementing contingency	Risks mature prior to risk review resolving the issue and defining the contingency plan.
	Learning from experience	Experience does not translate - delay caused by time spent on benefits management earlier in task	How does initial analysis translate to full analysis later in the project?	None	160	"We had that problem on the XXX project" – requirements on current project inherit historical requirements and impose the same problems without development learnt from previous projects.	Multiple problems are identified as similar to previous projects – similar requirements are applicable to this project with similar problems and no solution model.
	Risk	Task delivery becomes more complex	Multiple minor risks mature	Risk register and product / process FMEA	147	First requirements related minor risk that matures	Initial risk is not resolved before the next risk matures and additional resource is required to resolve.
	Quality	Deliverables are not accepted by customer	Insufficient evidence of quality procedures	Alignment of existing quality procedures to project requirements, identify gaps and introduce new procedures	140	Initial deliverable requires rework – quality / requirements not achieved	Management review of deliverables needed to redefine plan to deliver requirements and reset quality of work submitted to customer
	Stakeholders	Incorrect stakeholders involved	Fully defined	Stakeholder review at bid stage	140	Stakeholders not fully engaged with project objectives – responsibility for requirements not made clear	Stakeholders need to be "bought up to speed" at formal review – leading to rework or corrective action that impacts project progress.
	Project Team	Diverging interests cause project team to fragment – slowing progress	Will project teams have common interests	Selection process for contractors and suppliers	126	Need to deliver other objectives / work on other projects	Progress review delayed due to activities on other projects
	Stakeholders	Customer stakeholders incorrectly identified.	Failure to understand how the organisation of stakeholders will function	Project plan and stakeholder management	120	Need to revise project plan or review with stakeholders to resolve issues with meeting requirements.	Stakeholders organisation changes impact project progress and require review
	Contracts	Failure of supplier contracts	Supplier contract is not aligned to project requirements	Contract review to meet regulations within contract	120	Contractor delivers late or incorrect to requirements	Rework impacts progress

E.3 System selection

E.3.1 FMEA

Table 123: Research project (part 1) demonstration: system selection: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
System Selection								
	Troubleshooting	Potential problems are not identified and resolved leading to further issues	6	Across the whole project - Not done early enough in process	4	None	10	240
	Top Management Support	Task progress is delayed – impacting overall project delivery potentially leading to failure	7	Sub-contractors top management focus on higher value work – delivery to task requirements becomes 'last minute'	6	Sub-contractor contract / Trials plan	5	210
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	8	Lack of priority from top management for specific project	5	Not communicated by top management	5	200
	Project Change	Delivered product does not meet requirements	8	Group members avoid raising change requirements	5	Management review	5	200
	Benefits Management	Recommendation does not support maximum customer benefit	5	Broader application to product manufacture	4	None	10	200
	Stakeholders	Friction between partners makes the trials difficult	6	some partners were not aware of the level of commitment required	6	Top management commitment to support project	5	180
	Project Control / Process	Project deviates from plan – but is not identified by project controls until there is a significant issue	7	Project control / process does not accommodate uncertainty – insufficient contingency	5	Contingency plan / management reserve	5	175
	Communications	All issues around the project are likely to have an aspect of communications	7	Failure to communicate between actors	5	Regular communications meetings	5	175
	Learning from experience	Failure to identify lessons from the project organisation	5	Lack of improved development process for future tasks	3	None	10	150
	Contracts	Lack of communication leads to inappropriate contracts and problems to deliver the project	8	Understanding project requirements and structuring distribution between prime and sub-contract	6	Contract review	3	144

E.3.2 WS-TP analysis

Table 124: Research project (part 1) demonstration: system selection: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Points
System Selection							
	Troubleshooting	Potential problems are not identified and resolved leading to further issues	Across the whole project - Not done early enough in process	None	240	Systems selection problems remain active over multiple reviews	Known problem causes revision to project plan – systems selection process
	Top Management Support	Task progress is delayed – impacting overall project delivery potentially leading to failure	Sub-contractors top management focus on higher value work – delivery to task requirements becomes 'last minute'	Sub-contractor contract / Trials plan	210	Top management (sub-contractors) clearly focuses on other priorities, adversely impacting the systems selection process	Resources are allocated to other priorities – lack of focus on systems criteria
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	Lack of priority from top management for specific project	Not communicated by top management	200	Top management (prime-contractors) clearly focuses on other priorities, adversely impacting the systems selection process	Delays occur due to top management focus on other priorities
	Project Change	Delivered product does not meet requirements	Group members avoid raising change requirements	Management review	200	Slow recognition of change requests adversely impacting the systems selection process	Rework due to change requests
	Benefits Management	Recommendation does not support maximum customer benefit	Broader application to product manufacture	None	200	Project activities adversely impact benefits	No attention given to achieving benefits
	Stakeholders	Friction between partners makes the trials difficult	some partners were not aware of the level of commitment required	Top management commitment to support project	180	Partners have to be chased to progress basic aspects of systems selection tasks within project plan	System definition and selection not achieved
	Project Control / Process	Project deviates from plan – but is not identified by project controls until there is a significant issue	Project control / process does not accommodate uncertainty – insufficient contingency	Contingency plan / management reserve	175	Project status reports identify deviations that occurred earlier in schedule	Deviations unresolved
	Communications	All issues around the project are likely to have an aspect of communications	Failure to communicate between actors	Regular communications meetings	175	Communications are delayed	Causes rework
	Learning from experience	Failure to identify lessons from the project organisation	Lack of improved development process for future tasks	None	150	"That happened on XX project" – previous learning opportunities are not applied	Lessons from experience not applied
	Contracts	Lack of communication leads to inappropriate contracts and problems to deliver the project	Understanding project requirements and structuring distribution between prime and sub-contract	Contract review	144	Contract clauses dictate inappropriate actions	Contract review and re-issue

E.4 Hardware and Software development

E.4.1 FMEA

Table 125: Research project (part 1) demonstration: Hardware and software development: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Hardware and software development								
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	8	Lack of priority from top management for specific project	5	Not communicated by top management	5	200
	Project Change	Delivered product does not meet requirements	8	Group members avoid raising change requirements	5	Management review	5	200
	Stakeholders	*"This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required"* (Coley 2008)	6	*"It was apparent that some partners were not aware of the level of commitment that was required of them."* (Coley 2008)	6	Top management commitment to support project	5	180
	Project Change	Sub-contractors continue to progress incorrect work, and are then delayed on corrective action	7	Sub-contractors are not aware of task / project changes	5	Sub-contractor management activities	5	175
	Communications	All issues around the project are likely to have an aspect of communications	7	Failure to communicate between actors	5	Regular communications meetings	5	175
	Stakeholders	*"This meant that those working full time were constantly waiting for work from other members of the team before they could continue. This caused a sense of frustration"* (Coley 2008)	6	*"Some actors worked full time on the project whilst other actors worked part time."* (Coley 2008)	5	Top management commitment to support project progress	5	150
	Project Team	Project requirements are not prioritised by sub-contractors leading to delays	5	Sub-contractors allocate by highest demand	6	Sub-contractor management plan	5	150
	Contracts	Delay to start of work – or increased risk if work is commenced prior to contract	5	Customer delay's in placing contract	5	Contract is part of broader work package	6	150
	Contracts	Lack of communication leads to inappropriate contracts and problems to deliver the project	8	Understanding project requirements and structuring distribution between prime and sub-contract	6	Contract review	3	144
	Communications	*"This meant that frequently decisions made by one partner were not communicated with the rest of the team. This often resulted in a partner working on part of the design using the wrong dimensions for example"* (Coley 2008)	6	*"It appeared that some team members were unaware of the importance and need to communicate information, particularly when making design decisions."* (Coley 2008)	6	Need to maintain communication between team members	4	144

E.4.2 WS-TP analysis

Table 126: Research project (part 1) demonstration: Hardware and software development: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Hardware and software development							
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	Lack of priority from top management for specific project	Not communicated by top management	200	Ongoing activities impact progress for hardware and software development	Project replan to accommodate hardware and software issues impacts delivery
	Project Change	Delivered product does not meet requirements	Group members avoid raising change requirements	Management review	200	Hardware and software design requires additional data – impacting schedule	Need to revisit hardware and software design
	Stakeholders	*"This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required"* (Coley 2008)	*"It was apparent that some partners were not aware of the level of commitment that was required of them."* (Coley 2008)	Top management commitment to support project	180	Technical progress on hardware and software is impacted by stakeholder issues	Project replan to accommodate hardware and software issues impacts delivery
	Project Change	Sub-contractors continue to progress incorrect work, and are then delayed on corrective action	Sub-contractors are not aware of task / project changes	Sub-contractor management activities	175	Delay in distributing change information	H/w and s/w design revision required
	Communications	All issues around the project are likely to have an aspect of communications	Failure to communicate between actors	Regular communications meetings	175	Hardware and software progress not discussed in communications	Communications between hardware and software actors does not occur
	Stakeholders	*"This meant that those working full time were constantly waiting for work from other members of the team before they could continue. This caused a sense of frustration"* (Coley 2008)	*"Some actors worked full time on the project whilst other actors worked part time."* (Coley 2008)	Top management commitment to support project progress	150	Delays due to data supply between stakeholders	Reschedule due to stakeholder work patterns that were not recognised at initial planning
	Project Team	Project requirements are not prioritised by sub-contractors leading to delays	Sub-contractors allocate by highest demand	Sub-contractor management plan	150	Hardware and software requirements not achieved to initial plan	Need to replan
	Contracts	Delay to start of work – or increased risk if work is commenced prior to contract	Customer delay's in placing contract	Contract is part of broader work package	150	Extended period to achieve contract	Need for interim contract or alternative funding solution
	Contracts	Lack of communication leads to inappropriate contracts and problems to deliver the project	Understanding project requirements and structuring distribution between prime and sub-contract	Contract review	144	Defining h/w and s/w contracts requires more resource than initial plan	Review requires project replan – point of identification
	Communications	*"This meant that frequently decisions made by one partner were not communicated with the rest of the team. This often resulted in a partner working on part of the design using the wrong dimensions for example"* (Coley 2008)	*"It appeared that some team members were unaware of the importance and need to communicate information, particularly when making design decisions."* (Coley 2008)	Need to maintain communication between team members	144	Communications between hardware and software to ensure integration	Design change of causes rework to accommodate change that was not communicated

E.5 Condition of Supply

E.5.1 FMEA

Table 127: Research project (part 1) demonstration: Condition of supply: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Condition of supply								
	Benefits Management	Loss of contract	7	Failure to identify contract benefits and link them to requirements	3	None	10	210
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	8	Lack of priority from top management for specific project	5	Not communicated by top management	5	200
	Project Change	Delivered product does not meet requirements	8	Group members avoid raising change requirements	5	Management review	5	200
	Stakeholders	*"This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required"* (Coley 2008)	6	*"It was apparent that some partners were not aware of the level of commitment that was required of them."* (Coley 2008)	6	Top management commitment to support project	5	180
	Project Control / Process	Project not under control	7	Project management techniques / plan review	5	Project controls Process control plan	5	175
	Communications	All issues around the project are likely to have an aspect of communications	7	Failure to communicate between actors	5	Regular communications meetings	5	175
	Project Control / Process	Work cannot progress, or is progress incorrectly / dangerously	7	Facilities and equipment do not meet requirements	6	Change process impacts design – inconsistent measurements do not allow repeatability to be demonstrated	4	168
	Project Control / Process	Lack of contingency leads to out of scope resources being required to deliver objectives	7	Project control / process does not accommodate uncertainty – insufficient contingency	6	Assessment of management reserve	4	168
	Technology	Loss of contract	7	Inappropriate technology to meet requirements – e.g. customer EHS and legislative compliance	6	Requirements / contract review Compliance review at bid stage	4	168
	Benefits Management	Lack of learning not applied to current project or retained for future projects	4	How will the time spent here benefit the project later on?	4	None	10	160

E.5.2 WS-TP analysis

Table 128: Research project (part 1) demonstration: Condition of supply: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Condition of supply							
	Benefits Management	Loss of contract	Failure to identify contract benefits and link them to requirements	None	210	Sub-contract Condition of supply does not meet project requirements	Identify that Condition of supply to customer cannot be achieved
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	Lack of priority from top management for specific project	Not communicated by top management	200	Lack of recognition of Condition of supply requirements	Condition of supply requirements are delayed or ignored by top management
	Project Change	Delivered product does not meet requirements	Group members avoid raising change requirements	Management review	200	Change process identifies new / changed requirements late	Design review identifies failure to meet changed requirements
	Stakeholders	*"This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required"* (Coley 2008)	*"It was apparent that some partners were not aware of the level of commitment that was required of them."* (Coley 2008)	Top management commitment to support project	180	Misunderstanding between stakeholders on Condition of supply requirements	Stakeholder does not deliver / accept Condition of supply
	Project Control / Process	Project not under control	Project management techniques / plan review	Project controls Process control plan	175	Reporting process is behind project status	Reporting issues clearly misrepresented
	Communications	All issues around the project are likely to have an aspect of communications	Failure to communicate between actors	Regular communications meetings	175	Communications do not keep issues up to date	Rework required
	Project Control / Process	Work cannot progress, or is progress incorrectly / dangerously	Facilities and equipment do not meet requirements	Change process impacts design – inconsistent measurements do not allow repeatability to be demonstrated	168	Process issues lead to confusion on Condition of supply issues	Review identifies Condition of supply requirements failure
	Project Control / Process	Lack of contingency leads to out of scope resources being required to deliver objectives	Project control / process does not accommodate uncertainty – insufficient contingency	Assessment of management reserve	168	Reported status is out of date requiring investigation	Rework to resolve
	Technology	Loss of contract	Inappropriate technology to meet requirements – e.g. customer EHS and legislative compliance	Requirements / contract review Compliance review at bid stage	168	Technical solution not fully defined or needs review	Technical solution not available within prime / sub contractor – requiring additional sub-con
	Benefits Management	Lack of learning not applied to current project or retained for future projects	How will the time spent here benefit the project later on?	None	160	Condition of supply issues on other projects are identified on this project	Condition of supply issues requires solution to be identified (rather than applied solution from previous project and initial plan).

E.6 – Customer demonstration

E.6.1 FMEA

Table 129: Research project (part 1) demonstration: Customer demonstration: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Customer Demonstration								
	Project Team	Failure of team to deliver	6	Project team haven't fully grasped requirements – uncertainties in workload and completion	7	Scope and requirements communication to project team – understanding of risks	5	210
	Project Control / Process	Uncertainties remain unresolved leading to requirement for significant corrective action	7	Project control / process does not accommodate uncertainty – insufficient contingency	6	Design review	5	210
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	8	Lack of priority from top management for specific project	5	Not communicated by top management	5	200
	Project Change	Delivered product does not meet requirements	8	Group members avoid raising change requirements	5	Management review	5	200
	Stakeholders	*"This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required"* (Coley 2008)	6	*"It was apparent that some partners were not aware of the level of commitment that was required of them."* (Coley 2008)	6	Top management commitment to support project	5	180
	Top Management Support	Impacts task progress from sub-contractor and subsequent delivery to customer	6	Sub-contractors top management focus on higher value work – delivery to task requirements becomes 'last minute'	5	Sub-contractor progress reviews	6	180
	Risk	Sub-contract risks mature	6	Sub-contractors do not focus on risk issues	6	Sub-contractor risk review / contract	5	180
	Resources	Delay or unable to conduct trials	6	Sub-contractors resources are not available when required	6	Resource scheduling to deliver test plan	5	180
	Communications	All issues around the project are likely to have an aspect of communications	7	Failure to communicate between actors	5	Regular communications meetings	5	175
	Benefits Management	Benefits not realised	4	Broader application to product manufacture	4	None	10	160

E.6.2 WS-TP analysis

Table 130: Research project (part 1) demonstration: Customer demonstration: WS-TP

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Customer Demonstration							
	Project Team	Failure of team to deliver	Project team haven't fully grasped requirements – uncertainties in workload and completion	Scope and requirements communication to project team – understanding of risks	210	Initial planning for demonstration identifies further tasks to be resolved	Revision of demonstration scope
	Project Control / Process	Uncertainties remain unresolved leading to requirement for significant corrective action	Project control / process does not accommodate uncertainty – insufficient contingency	Design review	210	Uncertainties not resolved during initial planning / no process to resolve	Uncertainties remain unresolved at point of commitment to demonstrations
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	Lack of priority from top management for specific project	Not communicated by top management	200	Contractor not proactive towards demonstration	Contractors cannot support demonstration – rework / replan
	Project Change	Delivered product does not meet requirements	Group members avoid raising change requirements	Management review	200	Change requests impact demonstration scope	Demonstration not representative due to changes
	Stakeholders	*"This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required"* (Coley 2008)	*"It was apparent that some partners were not aware of the level of commitment that was required of them."* (Coley 2008)	Top management commitment to support project	180	Preliminary work with stakeholders raises additional issues for demonstration	Demonstration plans have to be revised to include stakeholders requirements
	Top Management Support	Impacts task progress from sub-contractor and subsequent delivery to customer	Sub-contractors top management focus on higher value work – delivery to task requirements becomes 'last minute'	Sub-contractor progress reviews	180	Subcontract raise issues e.g. supply of data or support impacting progress of demonstration plan	Sub-contract schedule extended
	Risk	Sub-contract risks mature	Sub-contractors do not focus on risk issues	Sub-contractor risk review / contract	180	Risks not resolved	Mitigation required
	Resources	Delay or unable to conduct trials	Sub-contractors resources are not available when required	Resource scheduling to deliver test plan	180	Resource issue identified	Progress impacted due to lack of resource
	Communications	All issues around the project are likely to have an aspect of communications	Failure to communicate between actors	Regular communications meetings	175	Demonstration information not communicated to stakeholders	Requirements not achieved due to communications failure
	Benefits Management	Benefits not realised	Broader application to product manufacture	None	160	Benefits gained from previous demonstrations not applied	Demonstration plan does not realise benefits

Appendix F Case study (5): Research Project (part 2): Industrialisation

F.1 Legislative and Environment, Health and Safety review

F.1.1 FMEA

Table 131: Research project (part 2) industrialisation: Legislative and Environment, Health and Safety review: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Legislative and Environmental, Health and Safety review								
	Project Change	Change in project scope fails to review legislation and Environmental, Health and Safety requirements	7	Failure to recognise that project change requires different Environmental, Health and Safety and legislation to be applied	6	Change management process and design review (local or at life cycle management maturity gate review)	4	168
	Stakeholders	Management of multiple levels of stakeholder leads to EHS failures	8	To many levels of stakeholder included in project structure	5	Environmental, Health and Safety requirements co-ordinated by prime contractor	4	160
	Quality	Replacement equipment requires learning curve to achieve acceptable standard	6	Obsolete equipment or breakdown requires replacement equipment to be introduced with impact on quality standards	5	Process changes require legislation and Environmental, Health and Safety review	5	150
	Quality	Extends task time – impacts project delivery	5	Change to customer requirements	6	Environmental, Health and Safety and legislation defined in requirements	5	150
	Time	Extended development time to implement solution	6	Legislation not identified as applicable	6	Review of known legislation by subject matter expert	4	144
	Quality	Product quality changes require legislation and Environmental, Health and Safety review	6	Change to product specification	6	Specification included in formal design reviews	4	144
	Quality	Product quality changes require legislation and Environmental, Health and Safety review	6	Change to conformance standards	6	Include planned changes in early process definition, anticipate potential changes and attempt to stay ahead of the legal minimum	4	144
	Stakeholders	Stakeholders don't recognise Environmental, Health and Safety requirements	7	Incorrect stakeholders identified at definition of industrialisation	4	Include Environmental, Health and Safety review of stakeholders as part of selection process	5	140
	Time	Extended development time to implement solution	6	Additional legislation introduced during development process	5	'watching brief' by Environmental, Health and Safety and legislation subject matter experts to identify new legislation	4	120
	Contracts	Contractual issues conflict with Environmental, Health and Safety requirements	5	Contractual definition did not make allowance for Environmental, Health and Safety and legislative change	6	Requirement for Environmental, Health and Safety and legislative compliance is embodied into contract	4	120

F.1.2 WS-TP analysis

Table 132: Research project (part 2) industrialisation: Legislative and Environment, Health and Safety review: WS-TP analysis

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Legislative and Environmental, Health and Safety review							
	Project Change	Change in project scope fails to review legislation and Environmental, Health and Safety requirements	Failure to recognise that project change requires different Environmental, Health and Safety and legislation to be applied	Change management process and design review (local or at Life Cycle Management (LCM) maturity gate review)	168	Task requires review and rework due to changes in Environmental, Health and Safety legislation	Design review identifies unresolved Environmental, Health and Safety issue
	Stakeholders	Management of multiple levels of stakeholder leads to Environmental, Health and Safety failures	To many levels of stakeholder included in project structure	Environmental, Health and Safety requirements co-ordinated by prime contractor	160	Difficulty in identifying stakeholders responsible for solving Environmental, Health and Safety issues.	Allocating responsibility impacts task progress
	Quality	Replacement equipment requires learning curve to achieve acceptable standard	Obsolete equipment or breakdown requires replacement equipment to be introduced with impact on quality standards	Process changes require legislation and Environmental, Health and Safety review	150	Training and learning curve impacts expected quality standards	Rework required
	Quality	Extends task time – impacts project delivery	Change to customer requirements	Environmental, Health and Safety legislation defined in requirements	150	Review of Environmental, Health and Safety to meet requirements change	Requirements change causes project to be re-baselined
	Time	Extended development time to implement solution	Legislation not identified as applicable	Review of known legislation by subject matter expert	144	Late identification of applicable legislation	Legislation change causes project to be re-baselined
	Quality	Product quality changes require legislation and Environmental, Health and Safety review	Change to product specification	Specification included in formal design reviews	144	Review of Environmental, Health and Safety legislation to meet quality requirements	New quality issue introduced requiring replanning / contingency to be applied
	Quality	Product quality changes require legislation and Environmental, Health and Safety review	Change to conformance standards	Include planned changes in early process definition, anticipate potential changes and attempt to stay ahead of the legal minimum	144	Quality review identifies issues	Product re-work needed to achieve revised Environmental, Health and Safety standards
	Stakeholders	Stakeholders don't recognise Environmental, Health and Safety requirements	Incorrect stakeholders identified at definition of industrialisation	Include Environmental, Health and Safety review of stakeholders as part of selection process	140	Lack of Environmental, Health and Safety requirement is identified after start of task	Task cannot proceed without correction of Environmental, Health and Safety requirement
	Time	Extended development time to implement solution	Additional legislation introduced during development process	'watching brief' by Environmental, Health and Safety & legislation subject matter experts (SME) to identify new legislation	120	Incomplete correlation of design solution to Environmental, Health and Safety requirements	Time schedule issues
	Contracts	Contractual issues conflict with Environmental, Health and Safety requirements	Contractual definition did not make allowance for Environmental, Health and Safety and legislative change	Requirement for Environmental, Health and Safety and legislative compliance is embodied into contract	120	Legislative issues require contract review	Contract revision and introduction of Environmental, Health and Safety or legislative change

F.2 – Requirements and Specification Review

F.2.1 FMEA

Table 133: Research project (part 2) industrialisation: Requirements and specification review: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Requirements and Specifications Review								
	Learning from experience	Repeat of previous known project failures	7	Failure to document previous requirements issues	6	None (Any previous experience?)	10	420
	Benefits Management	Loss of contract	8	Failure to identify contract benefits and link them to requirements	5	None	10	400
	Learning from experience	Repeat of previous known project failures	7	Failure to link documented experience to the current requirements	4	None	10	280
	Contracts	Failure of supplier contracts	8	Supplier contract is not aligned to project requirements	6	Contract review to meet regulations within contract	4	192
	Cost	Increased costs	6	Stakeholders do not accept or cannot commit to delivering requirements or to meet specification	6	Stakeholder selection process	5	180
	Stakeholders	Delay to tasks or project progress	6	Stakeholders require more time to respond to requirements and specifications	6	Stakeholder selection process	5	180
	Quality	Deliverables are not accepted by customer	7	Insufficient evidence of quality procedures	5	Alignment of existing quality procedures to project requirements, identify gaps and introduce new procedures	5	175
	Project Team	Lack of structure leads to project failure	7	Will stakeholders focus on other priorities?	6	Stakeholders have a vested interest	5	168
	Risk	Risks mature without contingency plan	7	Risk analysis across the task not conducted	6	Risk review	4	168
	Benefits Management	Loss of future contracts	8	Failure to draw experience from previous and current contracts to support future work	5	End of contract review. "lessons learnt" review / report	4	160

F.2.2 WS-TP analysis

Table 134: Research project (part 2) industrialisation: Requirements and specification review: WS-TP analysis

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Requirements and Specifications Review							
	Learning from experience	Repeat of previous known project failures	Failure to document previous requirements issues	None (Any previous experience?)	420	"we had that problem on XXX project"	Known solution not applied – leading to task /project issues
	Benefits Management	Loss of contract	Failure to identify contract benefits and link them to requirements	None	400	Resource creep	Beneficial topic not included in task review
	Learning from experience	Repeat of previous known project failures	Failure to link documented experience to the current requirements	None	280	"we had that problem on XXX project"	Known problem solution not included in project / task plan
	Contracts	Failure of supplier contracts	Supplier contract is not aligned to project requirements	Contract review to meet regulations within contract	192	Suppliers raise issues that impact progress	Supplier issues impact task progress
	Cost	Increased costs	Stakeholders do not accept or cannot commit to delivering requirements or to meet specification	Stakeholder selection process	180	Initial costs not based on formal quotes	Stakeholder / contractors decline to offer fixed price quote and increases costs
	Stakeholders	Delay to tasks or project progress	Stakeholders require more time to respond to requirements and specifications	Stakeholder selection process	180	Stakeholders do not respond in expected timescales	Stakeholders need to be chased and don't deliver to original agreed time scales
	Quality	Deliverables are not accepted by customer	Insufficient evidence of quality procedures	Alignment of existing quality procedures to project requirements, identify gaps and introduce new procedures	175	Unclear alignment of requirements to quality procedures	Design review identifies issues and applies corrective action
	Project Team	Lack of structure leads to project failure	Will stakeholders focus on other priorities?	Stakeholders have a vested interest	168	Stakeholders question project structure / team	Team has to be restructured
	Risk	Risks mature without contingency plan	Risk analysis across the task not conducted	Risk review	168	Risk impact was not recognised in risk review	Re-baseline risk review
	Benefits Management	Loss of future contracts	Failure to draw experience from previous and current contracts to support future work	End of contract review. "lessons learnt" review / report	160	Repetition of negative events that occurred in previous projects	Known topic where benefits could be realised is not applied and clear impact on task progress is identified

F.3 – Supply chain qualification

F.3.1 FMEA

Table 135: Research project (part 2) industrialisation: Supply chain qualification: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Supply chain qualification								
	Benefits Management	Loss of contract	7	Failure to identify contract benefits and link them to requirements	4	None	10	280
	Top Management Support	Delay on sub-contracted work	5	Sub-contractors top management focus on higher value work – delivery to task requirements becomes 'last minute'	7	Sub-contractors management are responsible for delivering the contract	6	210
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	8	Lack of priority from top management for supply chain qualification activities	5	Not communicated by top management	5	200
	Project Change	Delivered product does not meet requirements	8	Group members avoid raising change requirements	5	Management review	5	200
	Communications	All issues around the project are likely to have an aspect of communications	7	Failure to communicate between actors	5	Regular communications meetings	5	175
	Benefits Management	Loss of future contracts	8	Failure to draw experience from previous and current contracts to support future work	4	End of contract review. "lessons learnt" review / report	5	160
	Learning from experience	Repeat of previous known task / project failures	4	Failure to document previous requirements issues	4	None (Any previous experience?)	10	160
	Learning from experience	Repeat of previous known task / project failures	4	Failure to link documented experience to the current requirements	4	None	10	160
	Project Team	Resources unavailable to the project	5	Demand from other projects prioritises resource deployment	6	Matching requirements and resource	5	150
	Project Change	Uncertainties within supply chain lead to failure of qualification plan	5	Uncertainty of supply chain qualification plan	6	Change process needs to recognise and resolve uncertainty	5	150

F.3.2 WS-TP analysis

Table 136: Research project (part 2) industrialisation: Supply chain qualification: WS-TP analysis

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Supply chain qualification							
	Benefits Management	Loss of contract	Failure to identify contract benefits and link them to requirements	None	280	Issues arise in supply chain that could be avoided had benefits been applied	Issues impact project / task progress
	Top Management Support	Delay on sub-contracted work	Sub-contractors top management focus on higher value work – delivery to task requirements becomes 'last minute'	Sub-contractors management are responsible for delivering the contract	210	Sub-contractors do not progress work to the same focus as prime contractor	Prime contractor has to take direct action to prompt higher priority with sub-contractor top management
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	Lack of priority from top management for supply chain qualification activities	Not communicated by top management	200	Requirements for qualification of product delivered by supply chain is not defined by top management	Late definition of requirements leads to additional work and prompts change to project baseline
	Project Change	Delivered product does not meet requirements	Group members avoid raising change requirements	Management review	200	Communications of change to the supply chain	Supply chain does not deliver to post change standard
	Communications	All issues around the project are likely to have an aspect of communications	Failure to communicate between actors	Regular communications meetings	175	Communications have to be repeated with supply chain	Supply chain does not deliver to post communication standard
	Benefits Management	Loss of future contracts	Failure to draw experience from previous and current contracts to support future work	End of contract review. "lessons learnt" review / report	160	Known benefits not identified in supply chain	Supply chain requires restructuring leading to repeat of procurement process
	Learning from experience	Repeat of previous known task / project failures	Failure to document previous requirements issues	None (Any previous experience?)	160	Repeat of previous supply chain issues	Supply chain requires restructuring leading to repeat of procurement process
	Learning from experience	Repeat of previous known task / project failures	Failure to link documented experience to the current requirements	None	160	Repeat of previous supply chain issues	Supply chain requires restructuring leading to repeat of procurement process
	Project Team	Resources unavailable to the project	Demand from other projects prioritises resource deployment	Matching requirements and resource	150	Supply chain focuses on other issues	Supply chain delivery delayed
	Project Change	Uncertainties within supply chain lead to failure of qualification plan	Uncertainty of supply chain qualification plan	Change process needs to recognise and resolve uncertainty	150	Revision of supply chain delivery plan	Subsequent revision

F.4 – Process validation and demonstration

F.4.1 FMEA

Table 137: Research project (part 2) industrialisation: Process validation and demonstration: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Full process demonstration								
	Project Change	Delivered product does not meet requirements	8	Group members avoid raising change requirements	5	Management review	5	200
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	8	Lack of priority from top management for specific project	5	Not communicated by top management	5	200
	Stakeholders	*"This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required"* (Coley 2008)	6	*"It was apparent that some partners were not aware of the level of commitment that was required of them."* (Coley 2008)	6	Top management commitment to support project	5	180
	Communications	All issues around the project are likely to have an aspect of communications	7	Failure to communicate between actors	5	Regular communications meetings	5	175
	Stakeholders	*"This meant that those working full time were constantly waiting for work from other members of the team before they could continue. This caused a sense of frustration"* (Coley 2008)	6	*"Some actors worked full time on the project whilst other actors worked part time."* (Coley 2008)	5	Top management commitment to support project progress	5	150
	Communications	*"This meant that frequently decisions made by one partner were not communicated with the rest of the team. This often resulted in a partner working on part of the design using the wrong dimensions for example"* (Coley 2008)	6	*"It appeared that some team members were unaware of the importance and need to communicate information, particularly when making design decisions."* (Coley 2008)	6	Need to maintain communication between team members	4	144
	Contracts	Lack of communication leads to inappropriate contracts and problems to deliver the project	8	Understanding project requirements and structuring distribution between prime and sub-contract	6	Contract review	3	144
	Troubleshooting	Problems remain unresolved	7	Dispersed teams & sub-contractors make troubleshooting difficult	5	Team leaders review of group and local team management	4	140
	Project Team	Failure to communicate between project team members leads to problems	7	Sub-contract – relationship to prime	5	Prime contractor is not highest priority – not communicated by sub-contractor	4	140
	Stakeholders	Tasks / project fails due to lack of stakeholder commitment	7	Stakeholder commitment / other priorities	5	Contract review	4	140

F.4.2 WS-TP analysis

Table 138: Research project (part 2) industrialisation: Process validation and demonstration: WS-TP analysis

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Full process demonstration							
	Project Change	Delivered product does not meet requirements	Group members avoid raising change requirements	Management review	200	Product requirement not met leading to change request which is not raised	Previously rejected change request is required
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	Lack of priority from top management for specific project	Not communicated by top management	200	Definition of demonstration objectives are vague	Detail demonstration work cannot proceed
	Stakeholders	*"This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required"* (Coley 2008)	*"It was apparent that some partners were not aware of the level of commitment that was required of them."* (Coley 2008)	Top management commitment to support project	180	Stakeholders don't recognise their role in full process demonstration	Process demonstration has to be re-planned due to stakeholder action
	Communications	All issues around the project are likely to have an aspect of communications	Failure to communicate between actors	Regular communications meetings	175	Lack of communications for demonstration task	Topic within the task is not achieved due to communications failure
	Stakeholders	*"This meant that those working full time were constantly waiting for work from other members of the team before they could continue. This caused a sense of frustration"* (Coley 2008)	*"Some actors worked full time on the project whilst other actors worked part time."* (Coley 2008)	Top management commitment to support project progress	150	Part time staff availability impacts progress	Demonstration need to be re-planned
	Communications	*"This meant that frequently decisions made by one partner were not communicated with the rest of the team. This often resulted in a partner working on part of the design using the wrong dimensions for example"* (Coley 2008)	*"It appeared that some team members were unaware of the importance and need to communicate information, particularly when making design decisions."* (Coley 2008)	Need to maintain communication between team members	144	Information mismatch identified between partners	Impact of process demo planning or activities
	Contracts	Lack of communication leads to inappropriate contracts and problems to deliver the project	Understanding project requirements and structuring distribution between prime and sub-contract	Contract review	144	Terms of contract for demonstration are challenged	Contract terms not met
	Troubleshooting	Problems remain unresolved	Dispersed teams & sub-contractors make troubleshooting difficult	Team leaders review of group and local team management	140	Problems remain unresolved at pre-demonstration design review	Demonstration design solution needs to be revisited
	Project Team	Failure to communicate between project team members leads to problems	Sub-contract – relationship to prime	Prime contractor is not highest priority – not communicated by sub-contractor	140	Team members identify other priorities	Team members are not available due to other commitments
	Stakeholders	Tasks / project fails due to lack of stakeholder commitment	Stakeholder commitment / other priorities	Contract review	140	Stakeholders identify other priorities	Stakeholders are not available due to other commitments

F.5 – Design review

F.5.1 FMEA

Table 139: Research project (part 2) industrialisation: Design review: FMEA

Process Step	Potential Failure Modes	Potential Effects of Failure	Sev	Potential Cause(s) / Mechanism(s) of Failure	Occ	Current Process Controls	Det	RPN
Design review								
	Project Change	Delivered product does not meet requirements	8	Group members avoid raising change requirements	5	Management review	5	200
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	8	Lack of priority from top management for specific project	5	Not communicated by top management	5	200
	Stakeholders	*"This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required"* (Coley 2008)	6	*"It was apparent that some partners were not aware of the level of commitment that was required of them."* (Coley 2008)	6	Top management commitment to support project	5	180
	Communications	All issues around the project are likely to have an aspect of communications	7	Failure to communicate between actors	5	Regular communications meetings	5	175
	Stakeholders	*"This meant that those working full time were constantly waiting for work from other members of the team before they could continue. This caused a sense of frustration"* (Coley 2008)	6	*"Some actors worked full time on the project whilst other actors worked part time."* (Coley 2008)	5	Top management commitment to support project progress	5	150
	Contracts	Lack of communication leads to inappropriate contracts and problems to deliver the project	8	Understanding project requirements and structuring distribution between prime and sub-contract	6	Contract review	3	144
	Communications	*"This meant that frequently decisions made by one partner were not communicated with the rest of the team. This often resulted in a partner working on part of the design using the wrong dimensions for example"* (Coley 2008)	6	*"It appeared that some team members were unaware of the importance and need to communicate information, particularly when making design decisions."* (Coley 2008)	6	Need to maintain communication between team members	4	144
	Stakeholders	Tasks / project fails due to lack of stakeholder commitment	7	Stakeholder commitment / other priorities	5	Contract review	4	140
	Troubleshooting	Problems remain unresolved	7	Dispersed teams & sub-contractors make troubleshooting difficult	5	Team leaders review of group and local team management	4	140
	Project Team	Failure to communicate between project team members leads to problems	7	Sub-contract – relationship to prime	5	Prime contractor is not highest priority – not communicated by sub-contractor	4	140

F.5.2 WS-TP analysis

Table 140: Research project (part 2) industrialisation: Design review: WS-TP analysis

Process Step	Potential Failure Modes	Potential Effects of Failure	Potential Cause(s) / Mechanism(s) of Failure	Current Process Controls	RPN	Weak Signals	Tipping Point
Design review							
	Project Change	Delivered product does not meet requirements	Group members avoid raising change requirements	Management review	200	Change requests do not cover known issues	Design review action to resolve
	Top Management Support	Contractor management don't prioritise project tasks leading to delay or project failure	Lack of priority from top management for specific project	Not communicated by top management	200	Difficulty in obtaining top management availability for design review	Delay to design review due to top management impacts schedule
	Stakeholders	*"This caused friction between partners and made carrying out a whole system design difficult as significant levels of commitment are required"* (Coley 2008)	*"It was apparent that some partners were not aware of the level of commitment that was required of them."* (Coley 2008)	Top management commitment to support project	180	Stakeholders don't support design review activity	Design review delayed by stakeholder
	Communications	All issues around the project are likely to have an aspect of communications	Failure to communicate between actors	Regular communications meetings	175	Lack of communication activity to support design review	Design review scope not understood by actors
	Stakeholders	*"This meant that those working full time were constantly waiting for work from other members of the team before they could continue. This caused a sense of frustration"* (Coley 2008)	*"Some actors worked full time on the project whilst other actors worked part time."* (Coley 2008)	Top management commitment to support project progress	150	Delay in design review organisation – waiting on part time actors	Design review scheduled to meet availability of part time actors
	Contracts	Lack of communication leads to inappropriate contracts and problems to deliver the project	Understanding project requirements and structuring distribution between prime and sub-contract	Contract review	144	Contracted issues raised as part of design review scope	Contract issues impact design review
	Communications	*"This meant that frequently decisions made by one partner were not communicated with the rest of the team. This often resulted in a partner working on part of the design using the wrong dimensions for example"* (Coley 2008)	*"It appeared that some team members were unaware of the importance and need to communicate information, particularly when making design decisions."* (Coley 2008)	Need to maintain communication between team members	144	Different design standards / iterations presented at design review	Design review corrective action Design review re-run to complete actions
	Stakeholders	Tasks / project fails due to lack of stakeholder commitment	Stakeholder commitment / other priorities	Contract review	140	Stakeholder activities on other projects	Delay of design review due to stakeholder activities
	Troubleshooting	Problems remain unresolved	Dispersed teams & sub-contractors make troubleshooting difficult	Team leaders review of group and local team management	140	Problems identified but solution not implemented	Issues unresolved prior to design review
	Project Team	Failure to communicate between project team members leads to problems	Sub-contract – relationship to prime	Prime contractor is not highest priority – not communicated by sub-contractor	140	Team members using different standards of data	Not corrected prior to design review